

*42nd Northeast Regional
Stock Assessment Workshop (42nd SAW)*

Stock Assessment Report

**Part A: Silver Hake, Atlantic Mackerel,
& Northern Shortfin Squid
(CRD 06-09a)**

**Part B: Expanded Multispecies
Virtual Population Analysis
(MSVPA-X) Stock Assessment Model
(CRD 06-09b)**

May 2006

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- 06-02 **The 2005 Assessment of the Gulf of Maine Atlantic Cod Stock,** by R.K. Mayo and L.A. Col. March 2006.
- 06-03 **Summer Abundance Estimates of Cetaceans in US North Atlantic Navy Operating Areas,** by D.L. Palka. March 2006.
- 06-04 **Mortality and Serious Injury Determinations for Baleen Whale Stocks along the Eastern Seaboard of the United States, 2000-2004,** by T.V.N. Cole, D.L. Hartley, and M. Garron (web-only document). April 2006.
- 06-05 **A Historical Perspective on the Abundance and Biomass of Northeast Complex Stocks from NMFS and Massachusetts Inshore Bottom Trawl Surveys, 1963-2002,** by K.A. Sosebee and S.X. Cadrin. April 2006.
- 06-06 **Report of the GoMA GOOS Workshop on Objectives of Ecosystem Based Fisheries Management in the Gulf of Maine Area, Woods Hole, Massachusetts, 11-13 May 2004,** by S. Gavaris, W.L. Gabriel, and T.T. Noji, Co-Chairs. April 2006.
- 06-07 **Vida de los Pescadores Costeros del Pacífico desde México a Perú y su Dependencia de la Recolecta de Conchas (*Anadara* spp.), Almejas (*Polymesoda* spp.), Ostiones (*Crassostrea* spp., *Ostreola* spp.), Camarones (*Penaeus* spp.), Cangrejos (*Callinectes* spp.), y la Pesca de Peces de Escama en Los Manglares [The Fishermen's Lives in Pacific Coast Villages from Mexico to Peru, Supported by Landings of Mangrove Cockles (*Anadara* spp.), Clams (*Polymesoda* spp.), Oysters (*Crassostrea* spp., *Ostreola* spp.), Shrimp (*Penaeus* spp.), Crabs (*Callinectes* spp.), and Finfish],** by C.L. MacKenzie, Jr. and R.J. Buesa. April 2006.
- 06-08 **Bloom History of Picoplankter *Aureococcus anophagefferens* in the New Jersey Barnegat Bay-Little Egg Harbor System and Great Bay, 1995-1999,** by J.B. Mahoney, P.S. Olsen, and D. Jeffress. May 2006.

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**U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Marine Fisheries Service
Northeast Fisheries Science Center
Woods Hole, Massachusetts**

May 2006

Northeast Fisheries Science Center Reference Documents

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Assessment Report (42nd SAW/SARC)

Table of Contents (Volume A)

INTRODUCTION TO SAW-42 ASSESSMENT REPORT	1
A. ASSESSMENT OF SILVER HAKE	12
EXECUTIVE SUMMARY	12
1.0 TERMS OF REFERENCE	13
2.0 INTRODUCTION	14
3.0 THE FISHERY	16
Recreational Fishery	17
Commercial	17
Bycatch and Discards	17
4.0 SURVEY INFORMATION	19
Spatial patterns in NEFSC survey catches	20
Traditional” and “Special” strata sets for survey data	21
Mean weight and recruitment trends	21
Environmental effects on silver hake density and occurrence	22
Temporal patterns in stock distribution	24
What happened to the old fish?	25
Age reader experiments	26
Relationships between age and depth	27
Supplemental “Transect” bottom trawl survey	27
5.0 BIOMASS AND MORTALITY ESTIMATES	28
Trends in biomass and exploitation indices	29
Bounds for fishable biomass and fishing mortality	29
Bounds based on NEFSC and Supplemental surveys	29
Bounds based on historical landings and concurrent survey data	29
A bridge between the current and last assessment	29
6.0 OVERFISHING DEFINITIONS AND STATUS	30
Northern stock	31
Southern stock	31
7.0 STOCK PROJECTIONS	31
8.0 TOTAL ALLOWABLE LANDINGS (TAL)	31
9.0 SOURCES OF UNCERTAINTY AND NEW RESEARCH RECOMMENDATIONS	32
10.0 RESEARCH RECOMMENDATIONS FROM PREVIOUS ASSESSMENTS	32
11.0 LITERATURE CITED	33
SILVER HAKE TABLES	35
SILVER HAKE FIGURES	59
APPENDIX A1: Stock assessment team	109
APPENDIX A2: Supplemental “Transect” Survey	110
APPENDIX A3: Chairman and Rapporteur’s Report from Working Group Meeting	124
APPENDIX A4: Supporting information	127

B. ATLANTIC MACKEREL STOCK ASSESSEMENT	141
TERMS OF REFERENCE	141
EXECUTIVE SUMMARY	141
1.0 INTRODUCTION	142
2.0 THE FISHERY	143
Commercial Landings	143
Sampling Intensity	143
Catch-at-Age	144
Commercial Mean Weights	144
3.0 RESEARCH SURVEY ABUNDANCE INDICES FOR TREND	145
Growth	145
Predation Mortality	146
Mackerel Distribution	146
4.0 VPA CALIBRATION AND DIAGNOSTICS	146
5.0 ASAP FORWARD PROJECTION DESCRIPTION	147
6.0 ASAP INITIAL MODEL TRIALS AND RESULTS	148
7.0 BASE CASE MODEL	149
Total Biomass	150
Spawning Biomass	150
Fishing Mortality	150
Stock-Recruitment, Recruitment	150
Surplus Production	151
Precision of ASAP Estimates	151
Model Diagnostics	151
Retrospective Analysis	151
Projections	152
8.0 SENSITIVITY ANALYSIS	152
9.0 SARC-30 RESEARCH RECOMMENDATIONS (TOR 6)	153
10.0 RESEARCH RECOMMENDATIONS	154
11.0 LITERATURE CITED	155
MACKEREL TABLES	157
MACKEREL FIGURES	171
APPENDIX B1: Trial runs for the VPA and ASAP models	184
APPENDIX B2: Sensitivity Runs for Atlantic mackerel stock assessment	194
APPENDIX B3: Rapporteur's Report from Mackerel Working Group Meeting	200
 C. ASSESSMENT OF NORTHERN SHORTFIN SQUID	 202
EXECUTIVE SUMMARY	202
TERMS OF REFERENCE	203
1.0 INTRODUCTION	204
2.0 BACKGROUND	205
3.0 LANDINGS AND DISCARDS	207
Landings	207
Discards	209
Mean Body Size	211
4.0 RELATIVE ABUNDANCE AND BIOMASS INDICES	211

Research Surveys	211
Fishery Catch per Unit of Effort Indices.....	214
Fishing Effort.....	214
Trends in LPUE	215
5.0 ESTIMATION OF NATURAL MORTALITY	216
Maturation-Natural Mortality Model.....	216
6.0 BIOLOGICAL REFERENCE POINTS	217
Yield-per-recruit and egg-per-recruit models	217
7.0 STOCK SIZE AND FISHING MORTALITY RATES	218
In-season Assessment Model.....	218
8.0 CONCLUSIONS.....	219
9.0 RESEARCH RECOMMENDATIONS PAST AND PRESENT	219
10.0 ACKNOWLEDGEMENTS	220
11.0 REFERENCES	221
<i>ILLEX</i> TABLES.....	228
<i>ILLEX</i> FIGURES	246
APPENDIX C1: Comments from external reviewer	274
APPENDIX C2: Comments from SARC 42 Working Group meeting	276
APPENDIX C3: Maturation-Natural Mortality Model	278
APPENDIX C4: Per-recruit Models.....	278
APPENDIX C5: In-season Assessment Model	278

INTRODUCTION TO SAW-42 ASSESSMENT REPORT

The Northeast Stock Assessment Workshop (SAW) process has three parts: preparation of stock assessments by the SAW Working Groups and/or by ASMFC Technical Committees / Assessment Committees; peer review of the assessments by a panel of outside experts who judge the adequacy of the assessment as a basis for providing scientific advice to managers; and a presentation of the results and reports to the Regions managers.

Starting with SAW-39 (June 2004), the process was revised in two fundamental ways. First, the Stock Assessment Review Committee (SARC) is now a smaller panel with panelists provided by the University of Miami's Independent System for Peer Review (Center of Independent Experts, CIE). Second, the SARC no longer provides management advice. Instead, Council and Commission teams (e.g., Plan Development Teams, Monitoring and Technical Committees) formulate management advice, given that an assessment has been accepted by the SARC.

Reports that are produced following the SAW/SARC-41 meeting include: An *Assessment Summary Report* - a brief summary of the assessment results in a format useful to managers; this *Assessment Report* - a detailed account of the assessments for each stock; and the SARC panelist report - a summary of the panel's recommendations as well as appendices consisting of a report from each panelist. SAW/SARC assessment reports are available online at <http://www.nefsc.noaa.gov/nefsc/publications/series/crdlist.htm>. The CIE review reports

and assessment reports can be found at <http://www.nefsc.noaa.gov/nefsc/saw/>.

The 42nd SARC was convened in Woods Hole at the Northeast Fisheries Science Center, November 28 – December 4, 2005 to review three assessments (silver hake, Atlantic mackerel, *Illex* squid) and a multispecies predator-prey model known as MSVPA-X. The reviews were based on detailed reports produced by the SAW Northern Demersal, Coastal/Pelagic and Invertebrate Working Groups for silver hake, Atlantic mackerel, *Illex* squid assessment, and the ASMFC Multispecies Assessment Subcommittee and ASMFC Stock Assessment Committee for the MSVPA-X model.

This Introduction contains a brief summary of the SARC comments, a list of SARC panelists, meeting agenda, list of working group meetings and a list of attendees (Tables 1 – 4). Maps of the Atlantic coast of the USA are also provided (Figures 1 -3).

The SARC accepted part of the silver hake assessment. Three approaches were used in the assessment to estimate fishing mortality (F) and stock biomass. Two of these approaches were new and were designed to derive lower bounds for biomass and upper bounds for F: (1) a comparison of catches in the NEFSC survey with those in a Supplemental Finfish survey; and (2) a method based on the assumption that landings must be less than stock biomass. The third approach was the existing method which uses standard biomass and exploitation indices derived from NEFSC fall bottom trawl survey data and

commercial landings. The results of the two new approaches were not accepted by the SARC because the approaches depended on key assumptions that were not well supported. Thus, the assessment was based on the existing method which was used for determining stock status. The SARC concluded that although the silver hake assessment was able to evaluate stock status, more work should be done to evaluate the appropriateness of the existing threshold criteria.

The SARC accepted the Atlantic mackerel stock assessment, and indicated that the assessment was scientifically-sound and provided a credible basis for developing management advice. It was noted that estimates of fishing mortality and biomass from the new mackerel assessment model (ASAP) model had a retrospective pattern, raising concerns about whether these quantities were estimated well. The SARC felt that a suitable description was provided regarding the transition from an earlier assessment model to the ASAP model, but that more details and documentation should have been provided in the mackerel assessment report.

The *Illex* squid assessment was not able to estimate fishing mortality rate, stock biomass, or to determine stock status. The SARC indicated that the available data on *Illex* were not adequate to estimate these quantities; nevertheless, significant advances in modeling had taken place. The SARC advocated finding a new approach for evaluating overfishing, and deemed the existing criteria inappropriate for this short-lived species.

With respect to the MSVPA-X model, the reviewers concluded that all of the Terms of Reference were met; however, they stressed that it would not be appropriate to use the

present model as a basis for quantitative fishery management advice about menhaden or its predators. Rather, they felt that the MSVPA-X model was a valuable tool for understanding predator-prey dynamics and for exploring “what if” scenarios.

Due to its large size, this Assessment Report consists of two volumes. The first volume has the Working Group reports for the three stock assessments. The second volume has the MSVPA-X report. Members of the Working Groups are listed in Table 3. Sections of the Working Group reports that were not completed successfully, based on the opinion of the independent review panel (CIE), have been omitted by the SAW Chairman. The CIE report can be found at: (<http://www.nefsc.noaa.gov/nefsc/saw/>). In those places where text has been omitted, a note has been inserted informing the reader of this. The CIE’s decision to accept or reject assessment results was based on scientific criteria such as the quality of the input data that were available, quality of the data analysis and modeling, and whether the conclusions of the Working Group held up during the independent peer review SARC meeting. The CIE panel also considered whether the results were strong enough to serve as a basis for developing fishery management measures and advice.

Table 1. 42nd Stock Assessment Review Committee Panel.

42nd Northeast Regional Stock Assessment Workshop (SAW 42)
Stock Assessment Review Committee (SARC) Meeting

November 28 – December 4, 2005

SARC Chairman:

Dr. Andrew Payne
Centre for Environment, Fisheries and
Aquaculture Science, Lowestoft,
Suffolk NR33 0HT, UK (CIE)

SARC Panelists:

Dr. John Casey
Centre for Environment, Fisheries and
Aquaculture Science, Lowestoft,
Suffolk NR33 0HT, UK (CIE)

Dr. Vivian Haist
Consultant, 1262 Marina Way, Nanoose Bay,
British Columbia, Canada (CIE)

Dr. Yan Jiao
Department of Fisheries and Wildlife Sciences
Virginia Polytechnic Institute & State University
Blacksburg, VA, USA 24061 (CIE)

Table 2. Agenda, 42nd Stock Assessment Review Committee Meeting.

42nd Northeast Regional Stock Assessment Workshop (SAW 42)
Stock Assessment Review Committee (SARC) Meeting

Stephen H. Clark Conference Room – Northeast Fisheries Science Center
Woods Hole, Massachusetts

November 28 – December 4, 2005

AGENDA

TOPIC	PRESENTER	SARC LEADER	RAPPORTEUR
Monday, 28 Nov. (1:00 – 5:00 PM).....			
Opening			
Welcome	James Weinberg , SAW Chairman		
Introduction	Andrew Payne , SARC Chairman		
Agenda			
Conduct of Meeting			
Silver Hake (A)	Larry Jacobson	John Casey	Laurel Col
SARC Discussion	Andrew Payne		
Tuesday, 29 Nov. (8:30 AM – 12:00).....			
Mackerel (B)	William Overholtz	Vivian Haist	Chris Legault
SARC Discussion	Andrew Payne		
Tuesday, 29 Nov. (1:15 – 5:00 PM).....			
<i>Illex</i> squid (C)	Lisa Hendrickson	Yan Jiao	Rich Seagraves
SARC Discussion	Andrew Payne		

Wednesday, 30 Nov. (8:30 AM – 12:00)

MSVPA-X Model (D)

Matthew Cieri

Lance Garrison TBA

Patrick Kilduff

SARC Discussion

Andrew Payne

Wednesday, 30 Nov. (1:15 PM – 5:00)

Revisit Assessments and Model, as needed.

Thursday, 1 Dec. (8:30 AM –)

Revisit Assessments and Model, if needed.

SARC Report writing (closed)

Friday, 2 Dec. (8:30 AM –) – 4 Dec.

SARC Report writing. (closed)

Table 3. 42nd Stock Assessment Workshop, list of working groups and meetings.

<u>Assessment Group</u>	<u>Chair</u>	<u>Species</u>	<u>Meeting Date/Place</u>
SAW Invertebrate Working Group	Larry Jacobson, NMFS NEFSC	<i>Illex squid</i>	Oct. 3-4, 2005 Woods Hole
L. Hendrickson, NEFSC R. Seagraves, MAFMC Dvora Hart, NEFSC Teresa Johnson, Rutgers U. Eric Powell, Rutgers U. Glenn Goodwin, Seafreeze, Ltd. Jim Ruhle, MAFMC, F/V Daina R Phil Ruhle, NEFMC, F/V Sea Breeze Lynne Purchase, Imperial College, Lond			
SAW Northern Demersal, Coastal/Pelagic and Invertebrate Working Group	Ralph Mayo, NMFS NEFSC	<i>Illex squid, Atlantic mackerel, Silver hake</i>	Oct. 24-28, 2005 Woods Hole
J. Burnett, NEFSC S. Cadrin, NEFSC/SMAS L. Col, NEFSC D. Farnham, Industry Advisor F. Gregoire, Dept. of Fisheries and Oceans, Canada D. Hanselman, AFSC D. Hart, NEFSC L. Hendrickson, NEFSC L. Jacobson, NEFSC K. Lang, NEFSC C. Legault, NEFSC P. Nitschke, NEFSC M. Ortiz, SEFSC		E. Powell, Rutgers University P. Rago, NEFSC M. Radlinski, U. MA (SMAS) J. Ruhle, Industry Advisor R. Seagraves, MAFMC M. Terceiro, NEFSC M.B. Tooley, ECPH J. Weinberg, NEFSC A. Westwood, NEFSC S. Wigley, NEFSC B. Overholtz, NEFSC V. Wespestad, Industry Consultant	

The MSVPA-X Multispecies Assessment Subcommittee presented its work to the ASMFC Stock Assessment Committee on September 28, 2005. Membership:

MSVPA-X Multispecies Assessment Subcommittee

Matt Cieri – Subcommittee Chair, Maine Department of Marine Resources

Lance Garrison – Garrison Environmental Analysis and Research

Robert Latour – Virginia Institute of Marine Science

Behzad Mahmoudi – Florida Fish and Wildlife Conservation Commission

Brandon Muffley – New Jersey Department of Environmental Protection

Alexei Sharov – Maryland Department of Natural Resources

Doug Vaughan – National Marine Fisheries Service, Center for Coastal Fisheries and Habitat Research

ASMFC Stock Assessment Committee members present:

John Carmichael – Committee Chair, South Atlantic Fisheries Management Council

Matt Cieri – Subcommittee Chair, Maine Department of Marine Resources

Doug Grout – New Hampshire Department of Fish and Game

Kim McKown – New York Department of Environmental Conservation

Brandon Muffley – New Jersey Department of Environmental Protection

Mike Murphy – Florida Fish and Wildlife Conservation Commission

Des Kahn – Delaware Department of Natural Resources

Alexei Sharov – Maryland Department of Natural Resources

Doug Vaughan - National Marine Fisheries Service, Center for Coastal Fisheries and Habitat Research

Table 4. 42nd SAW/SARC, List of Attendees

Hassan Moustahfid, NEFSC
Michelle Traver, NEFSC
Loretta O'Brian, NEFSC
Laurel Col, NEFSC
Teresa Johnson, Rutgers U.
Gary Shepherd, NEFSC
Stacy Rowe, NEFSC
Sandy Sutherland, NEFSC
Susan Wigley, NEFSC
Chad Demerest, NEFMC
Jeff Kaelin, WFCNC
Jim Ruhle, MAFMC
Rich Seagraves, MAFMC
Paul Nitschke, NEFSC
Mary Radlinski, SMAST
Ralph Mayo, NEFSC
Mary Beth Tooley, ECPA
Matt Cieri, ME DMR
Chris Legault, NEFSC
Lisa Hendrickson, NEFSC
Devora Hart, NEFSC
Michael Fogarty, NEFSC
Patric Kilduff, ASMFC
J. Cox, Atl. Pel. Seafood
Peter Moore, Am. Pel. Assoc, NORPEL

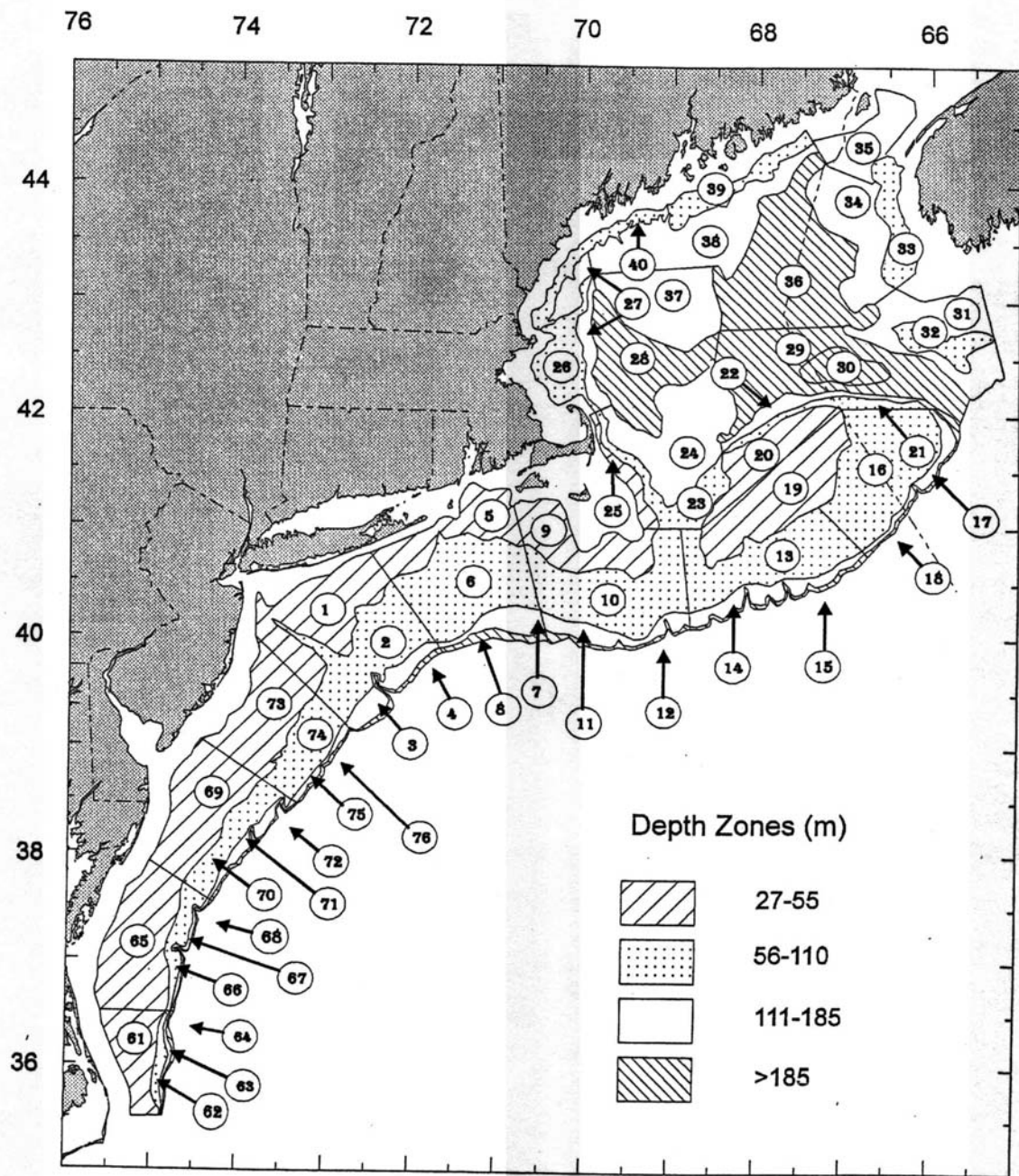


Figure 1. Offshore depth strata sampled during Northeast Fisheries Science Center bottom trawl research surveys.

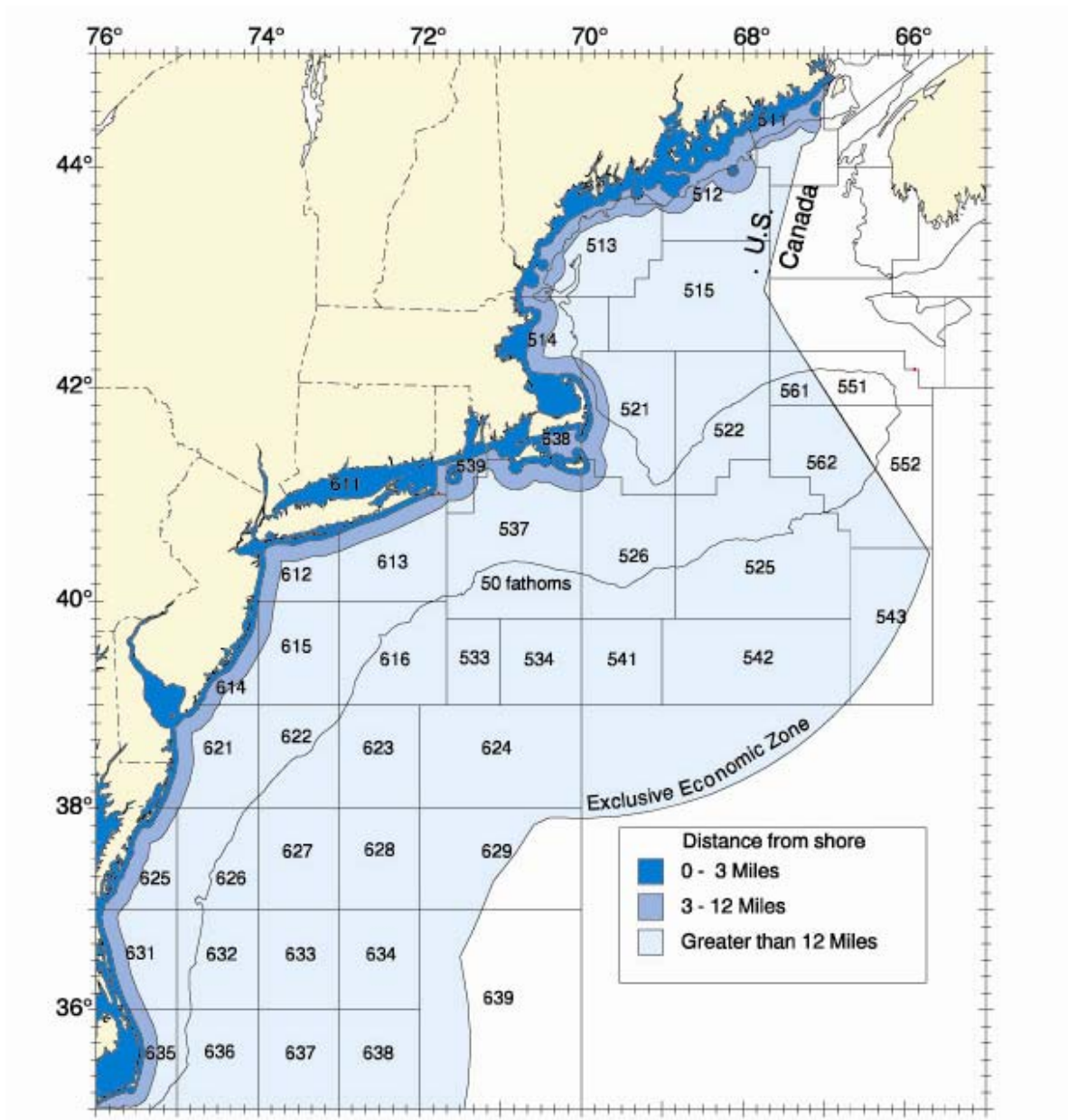


Figure 2. Statistical areas used for reporting commercial catches.

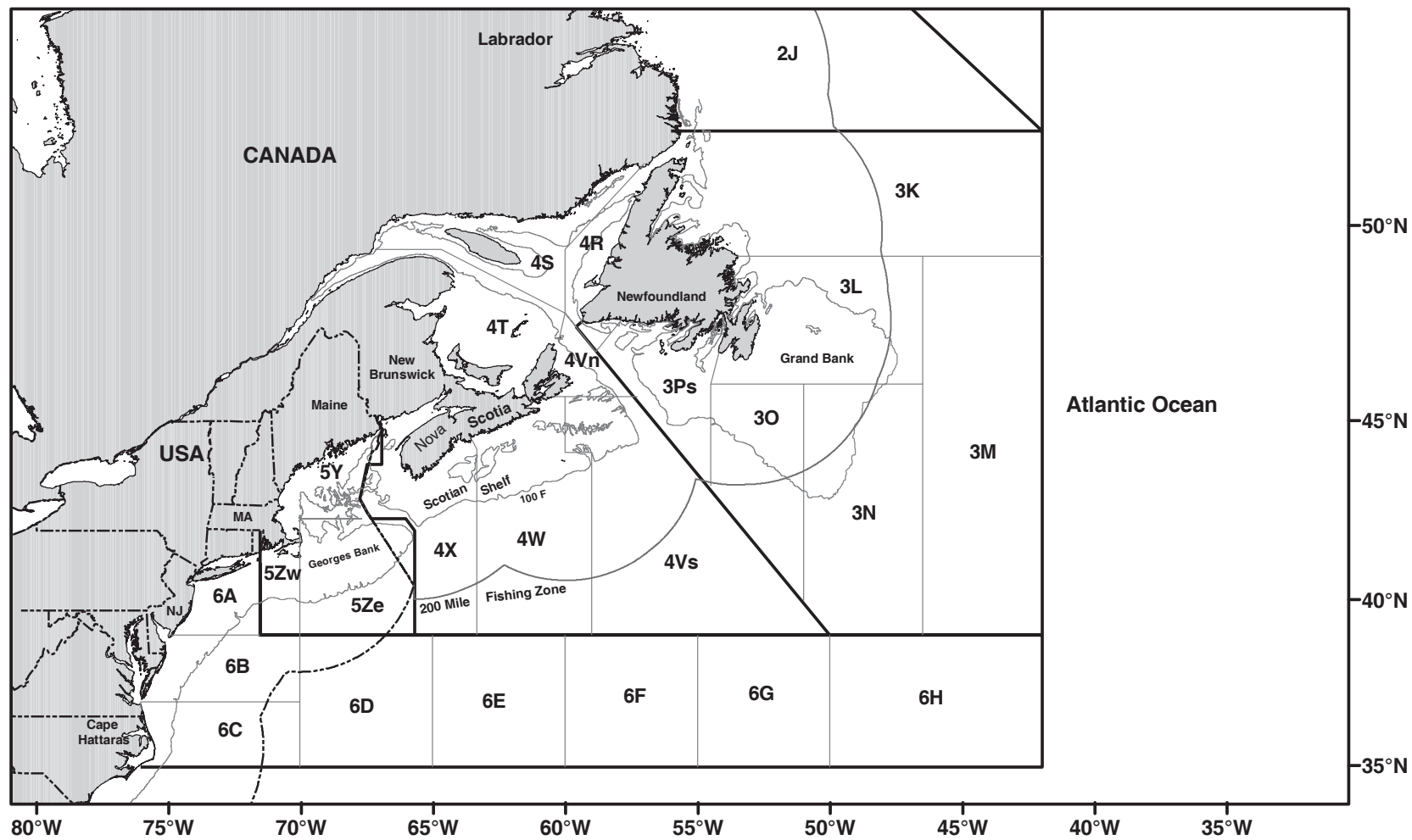


Figure 3. Catch reporting areas of the Northwest Atlantic Fisheries Organization (NAFO) for Subareas 3-6.

A. ASSESSMENT OF SILVER HAKE

EXECUTIVE SUMMARY

- 1) Overfishing definitions and biological reference points used in this assessment for the northern and southern stocks of silver hake are based on trends in three-year moving averages of fall survey biomass indices (delta mean kg/tow) and three-year averages of exploitation indices (landings / fall survey biomass index).
- 2) The biological reference points based on exploitation indices are new since the last assessment. They were developed during the interim by the New England Council's Whiting Monitoring Committee because fishing mortality estimates were not estimated for whiting in the last assessment and because it was not possible to use the original fishing mortality based reference points ($F_{0.1}$) in Amendment 12. The Whiting Monitoring Committee's proposal is a typical approach that was based on the original reference points to the extent possible. The new biological reference points were reviewed for this assessment and used because fishing mortality rates could not be estimated in this assessment either.
- 3) The northern stock of silver hake is not overfished and overfishing is not occurring. In particular, the three year average biomass index for 2002-2004 (6.72 kg/tow) was above the management threshold level (3.31 kg/tow) and near the target level (6.63 kg/tow). The three year average exploitation index for 2002-2004 (0.24) was below the management threshold and target level (2.57). The target and threshold reference points for defining overfishing in the northern stock are identical. The northern stock of silver hake was not overfished based on results from the last assessment (NEFSC 2001). Overfishing was not evaluated in the last assessment because fishing mortality rates were not estimated.
- 4) Based on current reference points, the southern stock of silver hake is not overfished and overfishing is not occurring. In particular, the three year average biomass index for 2002-2004 (1.37 kg/tow) was above the management threshold level (0.89 kg/tow) but below the target level (1.78 kg/tow). The three year average exploitation index for 2002-2004 (4.85) was below the management threshold level (34.39) and below the management target level (20.63). The southern stock of silver hake was overfished based on results from the last assessment (NEFSC 2001). Overfishing was not evaluated in the last assessment because fishing mortality rates were not estimated. The change in status is due to increases in stock biomass indices for the southern stock of silver hake.
- 5) The southern stock of silver hake was overfished based on results from the last assessment (NEFSC 2001). The change in status is due to increases in stock biomass indices for the southern stock of silver hake.
- 6) (EDITOR'S NOTE: THIS PART OF THE WORKING GROUP REPORT HAS BEEN OMITTED. IT WAS NOT ACCEPTED BY THE REVIEW PANEL.)

- 7) Fall survey recruitment indices show variable but generally increasing trends in the northern stock area since 1967. In the southern stock area, recruit and fishable biomass during fall surveys varied without trend.
- 8) Coast wide silver hake landings were less than 10 thousand mt per annually after 2002. During 2001-2004, coast wide silver hake discards averaged about 4000 mt y^{-1} (CV 17%) with at least 1,600 mt y^{-1} in the north and 2000 mt y^{-1} in the south on average during 2001-2004.
- 9) The most important uncertainties in management stem from clearly decreasing trends in abundance of relatively old and large individuals, despite low fishing mortality rates and relatively high biomass levels during recent years. Declines in abundance and occurrence of relatively old silver hake appear real and not due entirely to age reader errors, misidentification of offshore hake in surveys, or slower somatic growth. There is evidence of northward and offshore shifts in average location that may make relatively old and large silver hake less available to bottom trawl surveys. The possibility of increased natural mortality rates due to predation is a key area for future research.
- 10) Total allowable landings (TAL) for 2005 were calculated based on fall survey data through 2004 and exploitation index reference points. For the northern stock area during 2005, where the target and threshold reference points are the same, $TAL < 17.3$ mt. For the southern stock area during 2005 and based on the target reference point, $TAL = 28.3$ mt. For comparison, annual landings averaged 1.71 thousand mt in the north and 6.65 thousand mt in the south during 2002-2004.
- 11) Stock projections were not carried out but stock biomass levels are relatively high. Fishing mortality rates are very low in the north and probably low in the south also. Recent recruitments have been roughly average. Significant declines in stock biomass due to fishing are unlikely in the short term.

1.0 TERMS OF REFERENCE:

1. Characterize the commercial and recreational catch including landings and discards.

Recreational landings of silver hake were not estimated in this assessment but are minor based on estimates in the last assessment (Brodziak et al. 2001).

Discards were estimated in this assessment.

2. Estimate fishing mortality, spawning stock biomass, and total stock biomass for the current year and characterize the uncertainty of those estimates. If possible, also include estimates for earlier years.

(EDITOR'S NOTE: THIS PART OF THE WORKING GROUP REPORT HAS BEEN OMITTED. IT WAS NOT ACCEPTED BY THE REVIEW PANEL.)

3. Evaluate and either update or re-estimate biological reference points, as appropriate.

Reference points proposed by the New England Fishery Management Council's Whiting Monitoring Committee and used in overfishing definitions for silver hake during recent years were reviewed and used in this assessment.

4. As needed by management, estimate a single-year or multi-year TAC and/or TAL by calendar year or fishing year, based on stock biomass and target mortality rate.

TAL levels were calculated based on fall survey data through 2004 and exploitation index reference points.

5. If possible,
 - a. provide short term projections (2-3 years) of biomass and fishing mortality rate, and characterize their uncertainty, under various TAC/F strategies and
 - b. evaluate current and projected stock status against existing rebuilding or recovery schedules, as appropriate.

Based on a qualitative analysis, significant declines in stock biomass due to fishing are unlikely in the short term. It was not possible to carry out quantitative projection analyses.

6. Review, evaluate and report on the status of the SARC/Working Group Research Recommendations offered in previous SARC-reviewed assessments.

This information is provided at the end of the stock assessment report.

2.0 INTRODUCTION

Silver hake (*Merluccius bilinearis* or “whiting”) range from Newfoundland to South Carolina and are most abundant between Nova Scotia to New Jersey (Figure A1; Collette and Klein-MacPhee 2002). Silver hake are found over a broad range of depths ranging from shallow coastal areas to the continental slope. The offshore limit of habitat of silver hake habitat on the continental slope is uncertain but the species ranges to at least 400 m depth (Collette and Klein-MacPhee 2002). Silver hake are found in midwater as well as on the bottom but the extent to which they use the water column as habitat is unknown because most of the available information comes from bottom trawl gear.

As shown below, adult silver hake (age ≥ 2 y and TL ≥ 20 cm TL) tend to be distributed further offshore and further north than younger, smaller individuals. The size and age at which the offshore and northern shift in distribution occurs are approximately the same as the size and age at sexual maturity. Distribution patterns change seasonally as the adult population moves inshore with warmer water temperatures during the spring and summer to spawn near coastal juvenile habitat areas. Depth appears more important than temperature or season in determining distribution patterns because small individuals remain in shallow coastal areas despite substantial seasonal changes in water temperatures (warm during summer-fall and cool during winter-spring). Similarly, larger

individuals remain primarily in deeper water that is relatively warm during winter-spring and cool during summer-fall.

Silver hake are important as predators and prey in the food web of the northeast continental shelf ecosystem (Sissenwine and Cohen 1991). They feed mainly at night (Collette and Klein-MacPhee 2002). Small silver hake (< 20 cm TL) eat euphausiids, shrimp, amphipods and decapods. Larger silver hake eat fish (including other silver hake), crustaceans and squid. The shift in diet coincides with the onset of sexual maturity and offshore/north shift in distribution and cannibalism is common.

Two stocks of silver hake are currently assumed in managing the fishery and in stock assessments for silver hake in US waters (Figure A1). The northern stock area includes northern Georges Bank and the Gulf of Maine. The southern stock area includes southern Georges Bank, southern New England, and the Mid-Atlantic Bight. The two stock areas are based on differences in morphology (Almeida 1987), otolith shape (Bolles and Begg 2000), abundance trends, fishery patterns and the apparent break in silver hake habitat at Georges Bank.

Although management and stock assessments have been based on two stocks, silver hake along the northeast coast are likely one population with incomplete mixing between northern and southern areas (Brodziak et al. 2001). Larvae are pelagic and remain in the water column where they circulate freely for 1-5 months before metamorphosing to juvenile form and presumably settling to the bottom at about 1.7-2.0 cm TL (Lock and Packer 2004). North-south movement patterns are not well understood but it is likely, based on results from this assessment, that adults move around Georges Bank seasonally and depending on environmental conditions. The northern and southern stocks of silver hake are probably best viewed as management units.

Silver hake in Canadian waters are abundant enough to support a fishery.¹ The US and Canadian stocks of silver hake are probably linked to some degree and this is an important topic for future research.

The proportion of silver hake minimum swept area biomass in the northern area has varied substantially over time from less than 40% to more than 90% with proportions in the north generally increasing until recently (Figure A2). One of the key questions regarding silver hake is whether the shifts in distribution between the northern and southern areas are due to environmental effects on distribution or relatively high mortality in the southern area (Brodziak et al. 2001).

Silver hake grow rapidly (Figure A3). Growth rates vary over time and among areas but in an inconsistent fashion (Helser 1996; Brodziak et al. 2001). Based on Brodziak et al. (2001), growth has been rapid and almost linear in silver hake during recent years based on Brodziak et al. (2001). However, scarcity of older fish makes growth curves estimated from recent data difficult to compare to growth curves estimated from historic data (Brodziak et al. 2001). Growth and maturity rates may depend on stock biomass (Helser and Brodziak 1998).

¹ <http://www.frcc.ca/2004/SF2004.pdf>

Based on data from Canadian waters, growth of males and females is similar up to about 22 cm TL (Collette and Klein-MacPhee 2002), which coincides with the onset of sexual maturity (Figure A4). After sexual maturity, females grow more rapidly and to larger maximum sizes.

Survey age data for silver hake collected during 1973-2005 are from thin sectioned otoliths. Age data for earlier years are from whole otoliths and less reliable. Age reader experiments described in this assessment show that criteria used to age silver hake changed during 1973-2005. Historical age estimates are one or two years higher than estimates made recently from the same otoliths. The precision of age estimates decreases for older silver hake. Age data for silver hake are currently being re-audited to remove duplicate records discovered during this assessment.

There is considerable uncertainty about the potential longevity and underlying natural mortality rates silver hake. Brodziak et al. (2001) report that maximum ages observed in NEFSC fall and spring surveys declined from 14 y (corresponding to a natural mortality rate M of about 0.3 y^{-1} , Hoenig 1983) during the mid-1970's to 6 y recently (corresponding to a natural mortality rate of about 0.8 y^{-1} , Figure A5). One of the key questions regarding the stock is whether changes in maximum ages are due to environmental effects on availability of older fish to surveys, increased mortality, age estimation errors, or mis-identification of offshore hake (*M. albidus*).

3.0 THE FISHERY

Silver hake landings (Table 1) increased substantially during the 1960s due to directed fishing for silver hake by distant water fleets operating in US waters (Figure A6). During the 1990s, total silver hake landings were relatively low in comparison to historic values. Silver hake landings declined further to less than 10 thousand mt per year after 2002 (Figure A7).

Landings were almost entirely from the northern area prior to 1964 (Table A1 and Figures A8). After 1964, silver hake landings were mostly from the southern stock area.

Recreational Fishery

Silver hake once supported a recreational fishery in the Mid-Atlantic Bight (Fritz 1960) with annual landings of around 1,000 mt (2.2 million pounds) in the southern stock area. Recreational fishery landings decreased substantially in the 1970s and 1980s and are currently very low. Recreational landings of silver hake averaged only 18,000 fish per year during 1995-1999 (Brodziak et al. 2001).

Commercial Fishery

Directed commercial fishing for silver hake began in the 1920s. The fishery evolved over time from an inshore fishery using pound and trap nets to the modern otter trawl fishery (Fritz 1960; Table A2). The bulk of silver hake landings during recent years were from the southern stock area. In the northern stock area, landings are mostly from the Cultivator shoals, Gulf of Maine and the rest of Georges Bank (Table A2 and Figure A9). In the southern stock area landings are mostly from Southern New England and the Mid-Atlantic Bight (Table A2 and Figure A9). Landings data for years after 1994 are prorated to area of catch based on Vessel Trip Report (VTR) logbook data. Area of catch is identified in records for earlier years based on interviews by port samplers.

Silver hake were landed in six commercial market categories during 1995-2004 including the category “5095 (Large round)” that was new in 2004 (Table A2). Intensity of sampling was measured as number of length measurements divided by metric tons landed (Table A3). Sampling was highest (intensity > 1.5) for the hook & line gear group, gillnet gear group, and for the 5091 (King round) market category.

Length composition data for commercial landings indicate that the fishery has taken smaller silver hake since 1997 and that recruitment to the fishery begins to occur at about 20 cm TL (Figure A10). The shift in commercial length frequencies may be due to management measures, other changes in the fishery, or a change in the silver hake population.

Age composition data for commercial landings from Brodziak et al. (2001) show declines in proportions of older silver hake. Age data are not collected from the commercial fishery but commercial age composition can be inferred based on survey age data and commercial length composition data. Commercial and survey age composition data were not updated for silver hake in this assessment. Survey age data for silver hake used to construct age-length keys are currently being audited and should be ready for use in the next assessment.

Bycatch and Discards

Sea sampling data for 1989-1999 collected by observers on fishing vessels and reviewed by Brodziak et al. (2001) showed that discarding of silver hake captured by otter trawls occurred throughout the northern and southern stock areas. Discarding of silver hake by scallop dredges occurred in both northern and southern stock areas but discarding by sink gill nets occurred primarily in the northern stock area. Discard to kept (DK) ratios by weight (weight of silver hake discarded / weight of species landed) varied through time,

ranging from 0% to over 100% for the directed silver hake fishery (small mesh otter trawl, cod end mesh 3" or less) and for the non-directed fisheries (large mesh otter trawl, shrimp trawl, sink gill net, and scallop dredge). Variability in discard ratios may have been due to non-random coverage of the fleet, small sample sizes, or inherent variation in discard rates and practices.

New discard estimates for recent years (2001-2004) in this assessment were based on observer data and a ratio estimator first used for spiny dogfish (*Squalus acanthias*, NEFSC 2003). Estimates in this assessment were for recent years only because observer data coverage has increased in recent years and because recent discards were most important in evaluating the status of the silver hake resource.

The ratio estimator approach has several potential advantages including well defined statistical properties, relative simplicity and objective stratification based on landings data (i.e. it is not necessary to determine target species for tows or trips based criteria that are possibly arbitrary). However, ratio estimators are biased (see below) and the relative merits of discard estimators used in the Northeast (Rago et al. 2005) have not been fully evaluated.

Species groups and gear groups were used to tabulate and stratify observer and "landings" data (landings and haul weights in this analysis were haul weights for individual tows recorded by observers) at the trip level (Tables A4-A6). The species groups and gear groups used for silver hake were similar to the groups used for spiny dogfish (NEFSC 2003) with some modifications. All species potentially landed were assigned to a species group and all potential gear types are assigned to a gear group.

In the first step, kept (and presumably landed) weight $K_{G,S,T}$ is tabulated for each trip (T) in the observer database by species group (S) and gear group (G). Information about total silver hake discards on each trip ($D_{G,S,T}$) is retained but information about discard of other species is not. At the end of the first step, there is one record for each observed trip. The record contains total silver hake discards (which may be zero) and landings in each of the species groups. The sum of landings for all species groups equals total landings for the trip.

In the second step, the primary species group is determined based on the species group with highest landings. The secondary species group with second highest landings is used for diagnostic plots and identified as well (Rago et al. 2005). At the end of the second step, there is one record for each trip that contains the total silver hake discard, variables that identify the primary and secondary species group, a variable that identifies the gear group, and landings in the primary and secondary species groups.

The third step is to calculate DK ratios for each species group and gear group using the ratio estimator:

where $R_{G,S}$ is the DK ratio $R_{G,S} = \frac{\sum_T D_{G,S,T}}{\sum_T K_{G,S,T}}$ and the variance of the ratio estimator (Cochran 1977) is approximately:

$$Var(R_{G,S}) = \frac{Var(D_{G,S}) + R_{G,S}^2 Var(K_{G,S}) - 2R_{G,S} Cov(D_{G,S}, K_{G,S})}{n\bar{K}_{G,S}^2}$$

As shown in Cochran (1977) the ratio estimator is biased with:

$$bias = -\frac{Cov(R, \bar{K})}{\bar{k}} = -\frac{\rho\sigma_R\sigma_{\bar{K}}}{\bar{k}}$$

where \bar{K} is average landed weight estimated from observer data and \bar{k} is the true (unknown) value. Note that the absolute value of the bias increases with the variance and correlation in R and \bar{K} . It is therefore advantageous, in terms of minimizing both bias and variance, to pool data and choose primary species groups and gear groups that minimize the variance in these quantities.

In the final step, total landings in weight ($L_{G,S}$, based on dealer records) is calculated for each species gear and gear group. Total discard (Δ) is:

$$\Delta = \sum_G \sum_S L_{G,S} R_{G,S}$$

Assuming that landings are measured without error, the variance is:

$$Var(\Delta) = \sum_G \sum_S L_{G,S}^2 Var(R_{G,S})$$

For silver hake in this assessment, observer data for 2001-2004 were pooled to estimate one set of DK ratios and average annual discard estimates for 2001-2004. Pooling observer data for adjacent years, and use of relatively broad species groups and gear groups increased sample size and decreased variance. However, bias may have increased as well because of non-representative sampling and discard rates that probably varied among years, gear groups and primary species groups. The potential importance of these potential problems was not evaluated. However, the statistical (not sampling related) bias of ratio estimators is proportional to their CV (Cochran 1977) and it seemed reasonable to pool data sufficiently to reduce CVs.

Results

Mean annual discards during 2001-2004 are presented for gear and species groups with DK ratios > 0.0001 (Table A7). During 2001-2004, silver hake discards averaged about 3,820 mt y^{-1} (CV 17%). Trips with hakes and ocean pout as the primary species group in the other/unknown and bottom trawl gear groups had the highest DK ratios. The highest level of average annual silver hake discards were for crab/shrimps in shrimp trawls, and hakes and ocean pout in bottom trawls. See Appendix A4 for diagnostic plots (NEFSC 2003) presented to reviewers but not originally included in this assessment.

Discards were not estimated separately for northern and southern stock areas but it was possible to prorate estimates approximately for the most important primary species and gear groups with discards of at least 70 mt y^{-1} based on general knowledge about the fisheries (Table A7). On this basis, discards of silver hake in the northern stock area averaged at least 1,580 mt y^{-1} and discards in the southern stock area averaged at least 1998 mt y^{-1} during 2001-2004. For comparison, silver hake landings during the same period averaged 2,142 mt y^{-1} in the north and 7,153 mt y^{-1} in the south (Table A1).

4.0 SURVEY INFORMATION

Trends in survey biomass indices for the two silver hake stocks are evaluated in a subsequent section under the heading “Biomass And Fishing Mortality”. Analyses in this section are confined to trends in recruitment and related factors. Survey recruitment trends show that recruitment to the fishery (silver hake ≥ 20 cm TL) was at least average in the north during recent years. In the south, recruitment to the fishable stock fluctuated around average levels in recent years. Despite average or better recruitment, survey trends show reductions in abundance of relatively large silver hake and reduction in mean weight of individual fish that are analogous to reductions in abundance of old fish mentioned above.

A number of analyses were carried out to measure environmental effects on silver hake catches in NEFSC surveys, by size group, age, and stock area. Results suggest an ontogenetic shift at about the size and age of sexual maturity. In particular, relatively large and old fish are found further north and in deeper water (further offshore). Survey catches are highest at night, contrary to expectations, suggesting that silver hake have a reverse diel migration pattern. Depth seems to be more important than temperature in determining the distribution of silver hake. Small/young silver hake inhabit relatively shallow waters and larger/older silver hake inhabit deeper waters year around, despite large seasonal fluctuations in bottom temperatures.

Survey data are used to track the average position of silver hake in both stock areas and to test for trends in average position over time that might explain recent reductions in abundance of larger and older silver hake. Results generally suggest a shift in the distribution of larger fish to the north and offshore over time.

North-south movements of silver hake between stock areas is likely because the center of distribution for large fish in the northern area during the spring and small fish in the southern area during the fall is close to the boundary between the two stocks. It seems unlikely that silver hake in the north and south are separate populations but, depending on management goals, differences between the two areas are clear enough to justify use of the northern and southern regions as separate management areas.

Survey age data were examined to determine if relatively old silver hake observed historically might have been mis-aged or mis-identified offshore hake. Results indicate some imprecision in age estimation and a positive bias in historical ages (age reading criteria used historically result in ages 1-2 y higher than criteria used recently). The factors do not, however, completely explain the absence of older fish during recent years.

Spatial patterns in NEFSC survey catches

Maps showing locations and size of survey catches for all inshore and offshore strata sampled since 1979 (when inshore strata were first sampled consistently during spring and fall, Figures A11-A13) show how ubiquitous and widely distributed silver hake are in all seasons. Nearshore areas at 35°-38° N Lat. have a relatively high proportion of zero tows during fall and winter but not during spring. In addition, the southern flank of Georges Bank north of 40° N Lat. has a relatively high proportion of zero tows in winter,

but not during spring or fall. Silver hake were distributed in an apparently normal fashion during the most recent NEFSC surveys (Figures A14-A16).

None of the NEFSC bottom trawl surveys appear to cover the entire range of the silver hake stocks (Figures A11-A13). Catches were relatively high in deep water during winter, spring and fall along the 100-fathom contour and eastern edge of the area surveyed. In addition, catches from coastal areas north of 38° N Lat. were relatively high during spring and fall (inshore strata were not sampled during winter).

“Traditional” and “Special” strata sets for survey data

In this assessment, “traditional” strata sets are those used in previous assessments to describe trends in silver hake stock biomass (Brodziak et al. 2001). In particular, trends in abundance and biomass of silver hake for the northern stock area are traditionally measured using NEFSC fall and spring survey data from offshore strata 01200-01300 and 01360-01400 (NEFSC 2001). Strata 01610-01760 were not sampled during 1963-1966 so the survey biomass for sampled strata during 1963-1966 was increased by 1.8% in Brodziak et al. (2001), the long-term average proportion of silver hake biomass in strata 01610-01760. In this assessment, data for 1963-1966 were usually ignored. Previous assessments did not typically use inshore survey strata for silver hake, although inshore habitats are used by young and small silver hake, because inshore strata were not sampled consistently until 1979.

Different “special” strata sets were used for survey data in this assessment for environmental and trend analyses described below. Special strata sets for each survey and season were considered carefully with the goals of: 1) using as much information over the widest range of environmental conditions as possible; 2) using as many inshore strata as possible (small silver hake are most common in relatively shallow water; and 3) avoiding spurious results due to lack of sampling in some years. The primary criterion for choosing strata was consistency of sampling (i.e., was the stratum sampled during all years?). Winter and spring survey data were available through 2005. Fall survey data were available only through 2004.

Beginning in 1979, offshore and inshore strata were sampled consistently in the northern and southern stock areas (Tables A8-A11). The winter survey is carried out in offshore strata and in the southern stock area exclusively (Table A12). Based on this information, stock-specific strata sets were derived for the fall and spring surveys beginning in 1979 and for the winter survey beginning in 1992 (Table A13). In this assessment, special strata sets are consistently sampled inshore and offshore strata starting in 1979 (fall and spring surveys) or 1992 (winter surveys).

Mean weight and recruitment trends

Using the special strata sets, mean body weight of silver hake in NEFSC spring and fall surveys and north and south stock areas combined declined steadily during 1979 to 2005 (Figure A17). There were similar trends using the traditional strata sets for individual stock areas (results not shown). Mean weights were usually highest in the northern stock

area because larger fish tend to be found further north than smaller individuals. Survey length composition data show progressive reductions in abundance of large individuals (Figure A18).

Fall survey biomass indices (delta mean kg/tow) for recruit (< 20 cm TL) and fishable (\geq 20 cm TL) silver hake in the northern stock show variable but generally increasing trends in abundance since 1967 (Figures A19-A20). In the southern stock area, recruit and fishable abundance during fall surveys varied without trend (Figures A19-A20).

Based on spring survey data, recruit and fishable biomass peaked in both the north and south during 1973-1974 and then declined to relatively low levels by 1980 (Figures A19-A20). In the north, recruit and fishable biomass indices show noisy but generally increasing trends since the early 1980s. In the south, recruit biomass was low during 1982-1998 but may have increased somewhat during 1999-2005. Fishable biomass, in contrast, showed a variable but declining trend during the same period (Figures A19-A20).

Environmental effects on silver hake density and occurrence

Environmental effects on catchability of large or small silver hake may contribute to issues in interpreting survey data trends. The special set of survey strata were used in these analyses. A few tows in anomalously deep water (> 400 m), and tows with missing temperature, depth or time of day data were omitted. Analyses were carried out for the southern and northern stocks independently and combined.

Models were developed for the probability of occurrence of at least one silver hake in survey bottom trawl tows, and for numbers of silver hake caught in tows where at least one silver hake was caught. The first type of model measures probability of occurrence. The second measures density in areas where silver hake occur. Both types of models were fit to tow-by-tow data for individual length groups. Based on preliminary analyses, five cm length groups (1-5.9, 6-10.9, 11-15.9, 16-20.9, 21-25.9 and 26+ cm) were used in modeling. Very few small silver hake (1-5.9 cm TL) were captured during the spring survey in the northern stock areas. Therefore, the smallest size group was excluded from analyses for the northern stock area and for the northern and southern stock areas combined.

Relationships between environmental variables and the probability of occurrence were evaluated using step-wise logistic regression and generalized additive models (GAMs). Relationships between environmental variables and catch in positive tows were evaluated in a similar manner using step-wise log-linear regression and GAM models. The step-wise procedure used in both cases (step.gam in Splus) minimized the AIC statistic for a set of models.

The most complicated model considered for probability of occurrence was:

```
gam(P ~ as.factor(Y) + lo(T) + lo(D) + lo(L),  
family=binomial)
```

where the dependent variable P was either one (if at least one silver hake of appropriate size was caught in the tow) or zero (if no silver hake of appropriate size were caught). The most complicated model for density in positive tows was similar:

```
gam(log(d) ~ as.factor(Y) + lo(T) + lo(D) +  
lo(L))
```

where the dependent variable was the logarithm of the number of silver hake of appropriate size taken in the tow. In both models, the independent variables were year (Y), bottom temperature (T), average depth of the tow (D) and time of day (L , decimal EST time; e.g. 23.5 for 11:30 pm). The term $\text{lo}(x)$ is the loess locally linear scatter plot smoother fit with a span of 0.5 (Hastie and Tibshirani 1990).

Year (Y) was a categorical variable that was “forced” in each model (i.e. the step-wise procedure could not eliminate it). Other independent variables could enter the model either as a loess term, quadratic polynomial, linear term or could be omitted completely. Latitude and longitude were omitted in modeling because they were highly correlated with depth and bottom temperature and because the purpose was to understand environmental effects. Latitudinal and longitudinal patterns are explored in subsequent analyses (see below).

Results - probability of occurrence

Based on GAM model results (Table A14 and Figures A21-A25), small silver hake were most likely to be found in relatively shallow waters that tend to be relatively warm during autumn surveys and cool during spring and winter surveys. Depth and temperature distributions for positive tows confirm GAM results (Figures A26 to A28). Patterns related to depth and temperature were strongest for the southern stock probably because of the wider area sampled in the south.

Depth seemed more important than bottom temperature in predicting occurrence of silver hake because small individuals were found in relatively shallow water for both stocks during all surveys. Relationships between probability of occurrence for silver hake size and temperature differed in the winter, spring and fall surveys.

The probability of a positive tow for small silver hake was generally highest at night with the northern stock and fall survey being the notable exception (Table A14). This “reverse” diel pattern was first noted by Bowman and Bowman (1980) and is unexpected because most mesopelagic organisms migrate off bottom during the night time so that catch rates are highest during the day. Bowman and Bowman (1980) attributed low catch rates during the day to behavior of silver hake. They hypothesized that silver hake were very close to the bottom during the day and not efficiently captured by survey bottom trawls with roller gear, which might roll over them. Reverse diel migration patterns are not as strong for silver hake in winter surveys which use bottom trawls that have cables, rather than rollers, as ground gear (Tables A14-A15).

Results-catch in positive tows

GAM results for catches of silver hake in positive survey tows were generally similar to results for probability of occurrence although patterns were clearer for density with more significant loess terms in models (Table A15). In particular, density of small silver hake was highest in relatively shallow waters. The highest catches of large silver hake (> 21 cm) were at depths of at least 150 m at or near the offshore edge of the bottom trawl surveys. Bottom temperature, depth and time of day were significant in 30, 31 and 27 out of 31 total cases. All models with significant time of day effects predicted highest catch rates at night.

Temporal patterns in stock distribution

Mean depth, latitude, longitude and bottom temperature for silver hake of different sizes in the northern and southern stock areas were computed as catch weighted averages so that the latitude of a tow with a large catch received a higher weight than the latitude of a tow with a small catch (special strata set). Tows with zero catches were, in effect, omitted from the analysis because they received zero weight. Murawski (1993) and Overholtz and Friedland (2002) carried out similar analyses for latitude and longitude in a variety of species but used unweighted means. The weighted means used here should more accurately measure average position and environmental variables encountered by silver hake stocks. Linear regression analyses with year as the independent variable and mean latitude or longitude as the dependent variable were used to test for trends in location of silver hake. Both linear and loess regression lines were plotted to help visualize trends.

Results

Results (not shown) for trends in average temperature and depth supported results from the GAM model analysis because larger fish were found in deeper water that was relatively cold during fall surveys and relatively warm during spring and winter surveys. Variation in average temperature and depth was irregular and inconsistent. It did not indicate steady unidirectional trends or abrupt shifts in average depth or temperature of silver hake in any size group.

Results for trends in average location (latitude and longitude, Figures A29-A35) show that small silver hake (< 6 cm) in the northern stock area during the fall and southern stock area during the spring are located further south (lower mean latitude) than larger individuals. Larger individuals were located further offshore (at lower mean longitude) during the spring and winter surveys in the southern stock area.

Differences between location and size were clearest when the northern and southern stock areas combined (Figure A31 and A34). In particular, small silver hake tend to occur over inshore regions in the south while larger individuals are further north and offshore. As pointed out by reviewers, trends towards the north and offshore might be spurious and due to increasing abundance in the north of the northern and southern stocks are, in fact, independent populations.

Average latitude results indicate that substantial interchange of silver hake is likely between the northern and southern stock areas. The northern and southern stock areas are divided at approximately 41-42° N (Figure A1). Average locations of silver hake in the northern stock were generally close to the northern boundary of the southern stock area (Figures A29 and A32). Similarly, average locations of silver hake in the southern stock area during fall when water temperatures are warm were generally close to the southern boundary of the northern stock area (Figures A30).

Trends in mean bottom temperature over time were statistically significant (Table A16) in only two out of 40 possible cases. In particular, there were negative trends for two size groups in the fall survey with north and south stock areas combined. Trends in mean depth were statistically significant and positive in 12 out of 40 possible cases, most often for combined north and south stock areas during the fall.). Two apparently significant trends would be expected under the null hypothesis of no trends in bottom temperature using p -value 0.05.

Trends in latitude and longitude (Table A16 and Figures A29 to A35) indicate a general shift in the distribution of silver hake to the north and offshore. In particular, trends in mean latitude were statistically significant in 16 out of 40 cases. Trends in mean longitude were statistically significant in eight out of 40 cases (significant trends were positive in two cases and negative in eight cases). Two apparently significant trends would be expected under the null hypothesis of no trends in bottom temperature using p -value 0.05.

Trends in distribution may be confounded with changes in relative abundance of the north and south stocks because higher abundance in the north would result in a positive shift in mean latitude and a negative shift in mean longitude. Omitting cases with the southern and northern stocks combined, there were significant positive trends in mean latitude in ten cases and significant trends in mean longitude in six out of 30 cases (four negative trends and two positive trends, Table A16). One or two apparently significant trends would be expected under the null hypothesis of no trends in bottom temperature using p -value 0.05.

What happened to the old fish?

NEFSC survey age composition data for silver hake are currently being audited to remove some duplicate records. The provisional survey age data used here were corrected for obvious errors by the assessment authors and are meant only for use in this assessment.

Survey age composition data were not updated for silver hake in this assessment but age-specific abundance indices for silver hake from Brodziak et al (2001) show the declining trends in abundance of old fish despite trends for young fish that increased in recent years (Figure A36). Trends for relatively old silver hake are similar to results for relatively large fish (Figures A18-A20).

Several analyses indicate that normal variability in age reader data may exaggerate the apparent decline old silver hake in survey catches (see below). However, age data errors do not appear to be sufficient to completely explain the decline of old silver hake. As shown above, relative abundance of relatively large silver hake have declined in abundance as well.

Accounting for changes in criteria used to age silver hake (see below), the small number of old fish observed, and age estimation errors (see below), it appears likely that the apparent decline in maximum age from 14 to 6 years represents an actual decline from perhaps 10 to 6 years (see below). Based on the provisional survey data and original age estimates (Table A17), only sixteen “old” individuals (originally aged 11-14 years) have been observed out of roughly 100,000 age estimates for silver hake taken in NEFSC fall and spring surveys during 1973-2005. Sixteen age estimation errors of at least +2 y are plausible given experimental results shown below.

It is unlikely that old silver hake observed in surveys were all or mostly offshore hake, although the two species are similar in appearance (Collette and Klein-MacPhee 2002). Plots (not shown) of length versus age for all silver hake in the NEFSC survey database indicate that lengths at age for relatively old individuals were not anomalous. Geographic distributions of silver hake ages 8+ and offshore hake overlap (Figures A11-A12 and A37-A38). However, survey staffs are aware of potential misidentification problems with silver hake and are generally alert to the possibility of misidentification in areas where both species occur. Moreover, otoliths from the two species differ in shape (Figure A39) and age readers are able to distinguish otoliths from the two species.

An environmental change that shifted large silver hake into deeper water might explain the apparent decline in abundance (Brodziak et al. 2001). Relatively old and large silver hake are most common in deep water at the limit of depths sampled in NEFSC surveys (Figure A40-A41). Trends in the mean locations of large and presumably old silver hake have been noted (see above). However, despite a range of potential candidates (Brodziak et al 2001), no environmental factor with a definitive mechanism that might cause a shift to the north or offshore has been clearly identified.

Distribution plots for relatively old silver hake may indicate a north-south seasonal migration pattern (prepared after this assessment was completed and presented to reviewers, Appendix A4). During spring surveys, silver hake ages 8+ were found south of Georges Bank. During fall surveys, in contrast, silver hake ages 8+ were almost entirely north of Georges Bank.

Age reader experiments

Three experiments were undertaken to determine the precision of current and historic age estimates for silver hake in NEFSC surveys. In the first experiment, the primary age reader who estimated ages for silver hake in the 2001-2005 surveys re-aged a sample of 99 fish originally aged 1-5 y. The sample size at ages 3 y and older was small but percent agreement declines for older silver hake (Table A18).

In the second experiment, an alternate age reader who was experienced in ageing silver hake re-aged the 99 specimens used in the first experiment. Percent agreement between readings was generally lower than in the first experiment. As in the first experiment, the sample size was small for ages 3 y and older but percent agreement appears to have declined with age (Table A19).

In the third experiment, a sample of 17 fish from fall and spring surveys during 1973-1975, 1979 and 1982 originally aged 7-14 y were re-aged by the primary reader. Although sample size was small, it appears that current criteria for ageing silver hake would result in age estimates that would be 1-2 y lower than originally (Table A20).

Relationships between age and depth

Cumulative distributions for silver hake of different ages in fall and spring surveys (all strata and tows) show older fish in deeper water with an apparent shift to deep water during fall between ages 2-3 y (Figure A42). Cumulative distributions for age and temperature show older fish in relatively warm water during the fall and relatively cool water during the spring. Patterns for old fish are similar to those described above for large fish. In particular, depth seems to be more important than temperature in determining habitat for silver hake of different size.

Supplemental “Transect” bottom trawl survey

Bottom trawl data from the Supplemental Finfish Survey Targeting Mid-Atlantic Migratory Species were used in this assessment to estimate lower bounds for catchability in NEFSC bottom trawl surveys and to better characterize the distribution of silver hake in deep water along the shelf break (Tables A21-A22). The survey is described in general terms below and in Appendix A2. See HSRL (2005) for a more complete description.

Supplemental survey data for silver hake in this assessment were collected during March of 2004-2005 following transects along the northern flank of Baltimore and Hudson canyons (transects and tow locations were the same in all years, Figure A43). Data for 2003 were not used because silver hake and offshore hake were not distinguished in survey catch records. Baltimore canyon stations included in this analysis were in NEFSC survey strata 01020-01040. Hudson canyon stations were in NEFSC survey strata 01700-01720 (Figure A1). For simplicity in this analysis, “fixed” stations along transects are treated like random samples from NEFSC survey strata. Supplemental survey data used in the analysis were from fixed stations at target depths of 73, 91, 110, 146, 183, 229 and 274 m (40, 50, 60, 80, 100, 125 and 150 fathoms) that were occupied during the daytime. Deeper stations were occupied at night and omitted from this analysis except in estimating survey length composition.

The F/V Jason and Danielle (96 ft and 1080 hp) was used in 2003-2004 Supplemental surveys and the F/V Luke & Sarah (120 ft and 1500 hp) was used during 2005. The captain, bottom trawl gear and sampling protocols were the same in all surveys.

The commercial 4 seam box net bottom trawl used in supplemental surveys was the same in each year. The wingspread averaged about 67 m and head rope height averaged about 5.5 m. In contrast, the Yankee #36 standard bottom trawl currently used in NEFSC fall and spring surveys is smaller with a wingspread of about 12 m and head rope height of about 2 m. The commercial bottom trawl has a larger liner in the cod end (6 cm vs. 1.27 cm). The sweep of the commercial net is covered with 3 inch rubber cookies. The Yankee #36 bottom trawl has a combination of 5 and 15 inch rollers. The Yankee #36 bottom trawl used in NEFSC surveys catches more small whiting (< 20 cm TL, Figure A44).

Supplemental survey tows were made at 3 knots in a direction perpendicular to the slope and transect. NEFSC survey tows were made at 3.8 knots in the direction of the next station. The amount of wire let out was constant for all tows at the same depth. Distance towed in the Supplemental survey was determined based on a depth data from a depth sensor on the trawl.

Twenty cm is a reasonable lower bound for defining the fishable stock of silver hake. Silver hake captured by the commercial bottom trawl used in Supplemental surveys are seldom < 20 cm TL (Figure A45). Small silver hake are more common in NEFSC surveys but not often encountered in the areas of interest during the spring (Figure A44). In analyses that follow, catch was in kg per tow for silver hake ≥ 20 cm TL in NEFSC surveys and total catch for Supplemental surveys. Densities of silver hake (kg/km²) were calculated for each tow by dividing catch by area swept (Table A22).

Relationships between density and depth were generally similar for the two surveys (Figures A45-A47). Densities measured by the Supplemental Survey were substantially higher and less variable.

5.0 BIOMASS AND MORTALITY ESTIMATES

Three methods were used to characterize biomass and fishing mortality for silver hake in the northern and southern stock areas, and for the stocks combined. The first method is based on trends in biomass and exploitation indices that are calculated from landings and NEFSC fall survey data. The first method is the current standard and used by managers to specify management targets and thresholds and to define overfishing and overfished stock conditions. The second and third methods provide lower bound estimates for stock biomass and upper bound estimates for fishing mortality based on NEFSC survey, landings, discard and Supplemental survey data. The later two methods are new and have not been used previously. They are not intended to displace the standard method. Rather, they provide information about the scale (magnitude) of biomass and fishing mortality for silver hake.

Silver hake appear to be at relatively high biomass levels in both the northern and southern stock areas. Fishing mortality rates were low during recent years and much higher historically.

Trends in biomass and exploitation indices

Survey biomass trends for both the northern and southern stock areas (delta mean kg/tow for fall surveys during 1967-2004, calculated for “traditional” offshore strata) indicate that stock biomass is relatively high and near target levels used in management (Tables A22-A23 and Figures A48-A49). Relative exploitation indices (landings divided by the survey stock biomass index) indicate that fishing mortality rates are low in both stock areas and less than threshold levels used in management (Tables A22-A23 and Figures A48-A49).

A conventional age-structured stock assessment model was not used in this assessment for silver hake due to lack of time, uncertainty about stock structure, uncertainty about natural mortality stemming from trends in maximum age, ongoing audit of silver hake age data, low levels of fishing mortality during recent years (particularly in the north) which may complicate modeling, lack of a hypothesis regarding old fish to test in modeling, uncertainty about the magnitude of discards, a new stock assessment author, and the apparently misleading results from previous modeling efforts. In lieu of an age-structured stock assessment model, two approaches were used to estimate lower bounds for silver hake biomass and upper bounds for fishing mortality rates.

Bounds for fishable biomass and fishing mortality

(EDITOR’S NOTE: THIS PART OF THE WORKING GROUP REPORT HAS BEEN OMITTED. IT WAS NOT ACCEPTED BY THE REVIEW PANEL.)

Bounds based on NEFSC and Supplemental surveys

(EDITOR’S NOTE: THIS PART OF THE WORKING GROUP REPORT HAS BEEN OMITTED. IT WAS NOT ACCEPTED BY THE REVIEW PANEL.)

Bounds based on historical landings and concurrent survey data

(EDITOR’S NOTE: THIS PART OF THE WORKING GROUP REPORT HAS BEEN OMITTED. IT WAS NOT ACCEPTED BY THE REVIEW PANEL.)

A bridge between the current and last assessment

Trends in biomass and exploitation indices suggest that results from a virtual population analysis for silver hake in the previous assessment were overly pessimistic (NEFSC 2001). It appears that the virtual population analysis (VPA) used in the last assessment mistakenly interpreted trends in abundance of old silver hake as evidence of low abundance and high fishing mortality. A Bayesian surplus production model in the last assessment appears to have given more plausible results with generally increasing biomass trends for the stock as a whole.

6.0 OVERFISHING DEFINITIONS AND STATUS

Overfishing definitions and biological reference points used by managers for the northern and southern stocks of silver hake are summarized below and in NEFMC (2002).

Summary of biological reference points used in overfishing definitions for silver hake. The new exploitation based target for silver hake in the southern stock area is 60% of the threshold, F_{MSY} proxy level. The biomass based reference points include an adjustment made in NEFSC (2001) to accommodate recalculation of survey biomass indices.

Stock	Biomass target (B_{MSY} proxy, average delta mean kg tow for NEFSC fall survey during 1973-1982)	Biomass threshold (1/2 B_{MSY} proxy, delta mean kg tow in NEFSC fall survey)	New exploitation index reference points (landings / biomass index)		Original fishing mortality (F) based reference points in Amendment 12 (y^{-1})	
			Target	Threshold (F_{MSY} proxy)	Target	Threshold (F_{MSY} proxy)
North	6.63	3.31	2.57	2.57	$F < F_{0.1}$	$F_{0.1} = 0.41$
South	1.78	0.89	20.63	34.39	$F < F_{0.1}$	$F_{0.1} = 0.39$

The B_{MSY} proxies and biomass reference points used for both stocks of silver hake in this assessment and in NEFSC (2002) are based on average catch rates in the NEFSC fall survey (delta mean kg/tow) during 1973-1982, a period of relative stability in the fishery (Figure A48-A49). The biomass reference points for silver hake are compared to the most recent three-year averages of fall survey biomass (delta mean kg/tow) to determine if either stock is overfished.

The F_{MSY} proxies and associated reference points used for silver hake in this assessment and in NEFSC (2002) are based on exploitation indices (landings / fall survey delta mean kg/tow), are new since the last assessment (NEFSC 2001), and differ from the reference points in Amendment 12 of the Northeast Multispecies Fishery Management Plan. In particular, the F_{MSY} proxies and fishing mortality reference points used for silver hake in this assessment are based on exploitation indices (landings / fall survey delta mean kg/tow) during 1973-1982, a period of relative stability in the fisheries that is already used to define biomass reference points (Figure A48-A49). The new reference points for silver hake are compared to the most recent three-year averages of the exploitation rates indices (landings over delta mean kg/tow) to determine if overfishing is occurring in either stock.

The new reference points based on exploitation indices were developed since the last assessment and used annually by the New England Council's Whiting Monitoring Committee because fishing mortality rates were not estimated for whiting in the last assessment (NEFSC 2001) and because it was not possible to use the original fishing mortality based reference points ($F_{0.1}$) in Amendment 12.

The Whiting Monitoring Committee's new reference points were reviewed and used in this assessment because fishing mortality rates were not estimated. The exploitation index approach is common in northeast fisheries when fishing mortality cannot be

estimated, and it was based on the original reference points to the extent possible. The exploitation based target for the southern stock is set at 60% of the F_{MSY} proxy and is more risk averse than the original approach in Amendment 12. The target and threshold reference points for defining overfishing in the northern stock are identical.

Northern stock

The northern stock of silver hake is not overfished and overfishing is not occurring (Table A22 and Figure A48). In particular, the three-year average biomass index for 2002-2004 (6.72 kg/tow) was above the management threshold level (3.31 kg/tow) and near the target level (6.63 kg/tow). The three-year average exploitation index for 2002-2004 (0.24) was below the management threshold and target level (2.57).

The northern stock of silver hake was not overfished based on results from the last assessment (NEFSC 2001). Overfishing was not evaluated in the last assessment because fishing mortality rates were not estimated.

Southern stock

Based on current reference points, the southern stock of silver hake is not overfished and overfishing is not occurring (Table A23 and Figure A49). In particular, the three year average biomass index for 2002-2004 (1.37 kg/tow) was above the management threshold level (0.89 kg/tow) and near the target level (1.78 kg/tow). The three year average exploitation index for 2002-2004 (4.85) was below the management threshold level (34.39) and below the management target level (20.63).

The southern stock of silver hake was overfished based on results from the last assessment (NEFSC 2001). Overfishing was not evaluated in the last assessment because fishing mortality rates were not estimated. The change in status is due to increases in stock biomass indices for the southern stock of silver hake.

7.0 STOCK PROJECTIONS

Stock projections were not carried out because current age structure, abundance and were not estimated biomass in absolute terms. However, stock biomass levels are relatively high and current fishing mortality rates are very low in the north and probably low in the south also. Recent recruitments have been roughly average. Uncertainties exist because old fish are still absent and the cause is unknown. Given these factors, a qualitative analysis suggests that significant declines in stock biomass due to fishing are unlikely in the short term.

8.0 TOTAL ALLOWABLE LANDINGS (TAL)

Total allowable landings (TAL) for 2005 were calculated based on fall survey data through 2004 and exploitation index reference points (Table A27). In particular, target exploitation indices (landings / three year average survey) were multiplied by the most recent three-year average survey abundance index to estimate landings at the target exploitation level. Assuming that the reference points are exact, CVs measuring uncertainty in TAL calculations are the same as the CV for the three year average survey.

For the northern stock area during 2005, where the target and threshold reference points are the same, $TAL < 17.3$ mt. For the southern stock area during 2005 based on the target reference point, $TAL = 28.3$ mt. For comparison, annual landings averaged 1.71 thousand mt in the north and 6.65 thousand mt in the south during 2002-2004.

9.0 SOURCES OF UNCERTAINTY AND NEW RESEARCH RECOMMENDATIONS

The most important uncertainties stem from clearly decreasing trends in abundance of relatively old and large individuals. These reductions have occurred despite apparently normal growth patterns, low fishing mortality rates and relatively high biomass levels during recent years. The possibility of increased natural mortality rates due to predation or other ecosystem level effect is a key area for future research.

Survey data indicate that relatively large silver hake may move around Georges Bank from the southern stock area to the northern. Uncertainty about north-south movements of adult silver is important because of uncertainty about linkages between the northern and southern stock areas.

Considerable amounts of silver hake biomass may occur midwater and on the bottom at depths that are not effectively sampled by NEFSC bottom trawl surveys. Stock biomass would be better estimated if more information about use of midwater habitat information was available and if the lower depth distribution of silver hake was determined.

10.0 RESEARCH RECOMMENDATIONS FROM PREVIOUS ASSESSMENTS

- 1) Develop survey information that covers the offshore range of the population. *The Supplemental ("Transect") survey during 2003-2005 sampled relatively deep water along several transects.*
- 2) Conduct surveys of spawning aggregations on the southern flank of Georges Bank. *This research recommendation was not addressed.*
- 3) Investigate bathymetric demography of population. *The current assessment includes extensive analysis of relationships between location, depth, size and age based on bottom trawl survey data.*
- 4) Investigate spatial distribution, stock structure and movements of silver hake within Georges Bank, the Gulf of Maine, and the Scotian shelf in relation to physical oceanography. *The current assessment includes extensive analysis of survey data to determine trends in locations of highest silver hake density (catch*

weighted mean latitude and longitude) and to determine environmental factors that affect density of silver hake of different sizes and at different times of the year.

- 5) Quantify age-specific fecundity of silver hake. *This research recommendation was not addressed.*

11.0 LITERATURE CITED

- Almeida, F. 1987. Stock identification of silver hake in the New England-Middle Atlantic area. *N. Amer. J. Fish. Mgmt.* 7: 169-186.
- Bolles, K.L., and G.A. Begg. 2000. Distinction between silver hake (*Merluccius bilinearis*) stocks in U.S. waters of the Northwest Atlantic based on whole otolith morphometrics. *Fish. Bull.* 98: 451-462.
- Bowman, R. and E. Bowman. 1980. Diurnal variation in the feeding intensity and catchability of silver hake. *Can. J. Fish. Aquat. Sci.* 37: 1565-1572.
- Brodziak, J.K.T., E.M. Holmes, K.A. Sosebee, and R.K. Mayo. 2001. Assessment of the silver hake resource in the northwest Atlantic in 2000. NEFSC Ref. Doc. 01-03.
- Cochran, W.G. 1977. Sampling techniques. John Wiley & Sons, NY.
- Collette, B.B., and G. Klein-MacPhee. 2002. Bigelow and Schroeder's fishes of the Gulf of Maine. Smithsonian Institution Press, Washington, DC.
- Fritz, R. 1960. A review of the Atlantic coast whiting fishery. *Commer. Fish. Rev.* 22: 1-11.
- Hastie, T.J., and R.J. Tibshirani. 1990. Generalized additive models. Chapman and Hall, New York, NY.
- Helser, T.E. 1996. Growth of silver hake within the U.S. continental shelf ecosystem of the northwest Atlantic Ocean. *J. Fish. Biol.* 48: 1059-1073.
- Helser, T., and J. Brodziak. 1998. Impacts of density-dependent growth and maturation on assessment advice to rebuild depleted U.S. silver hake stocks. *Can. J. Fish. Aquat. Sci.* 55: 882-892.
- Hoenig, J. 1983. Empirical use of longevity data to estimate mortality rates. *Fish. Bull.* 82: 898-903.
- HSRL (Haskin Shellfish Research Laboratory). 2005. Supplemental finfish survey targeting Mid-Atlantic Species. March 2005 Supplementary Survey Cruise Report. Haskin Shellfish Research Laboratory, Port Norris, NJ.

- Lock, C.L., and D.B. Packer. 2004. Essential fish habitat source document: silver hake, *Merluccius bilinearis*, life history and habitat characteristics (2nd edition). NOAA Tech. Memo. NMFS-NE-186.
- Murawski, S.A. 1993. Climate change and marine fish distributions: forecasting from historical analogy. *Trans. Am. Fish. Soc.* 122: 647-658.
- New England Fishery Management Council (NEFMC). 2002. Final 2002 stock assessment and fishery evaluation (SAFE) report for small mesh multispecies (whiting, red hake and offshore hake).
- Northeast Fisheries Science Center (NEFSC). 2001. Report of the 32nd Northeast Regional Stock Assessment Workshop (32nd SAW): Stock Assessment Review Committee (SARC) consensus summary of assessments. *Northeast Fish. Sci. Cent. Ref. Doc.* 01-05. 289 pp.
- Northeast Fisheries Science Center (NEFSC). 2002. Longfin squid. *In*: Report of the 34th Northeast Regional Stock Assessment Workshop (34th SAW): Stock Assessment Review Committee (SARC) consensus summary of assessments. *Northeast Fish. Sci. Cent. Ref. Doc.* 02-06. 346 pp.
- Northeast Fisheries Science Center (NEFSC). 2003. Report of the 37th Northeast Regional Stock Assessment Workshop (37th SAW): Stock Assessment Review Committee (SARC) consensus summary of assessments. *Northeast Fish. Sci. Cent. Ref. Doc.* 03-16. 597 pp.
- Overholtz, W. J., and K. Friedland. 2002. Recovery of the Gulf of Maine-Georges Bank Atlantic Herring (*Clupea harengus*) complex: perspectives based on bottom trawl survey data. *Fish. Bull.* 100: 593-608.
- Rago, P.J., S.E. Wigley, M.J. Fogarty. 2005. NEFSC bycatch estimation methodology: allocation, precision and accuracy. *Northeast Fisheries Science Center Ref. Doc.* 05-09.
- Sissenwine, M., and E. Cohen. 1991. Resource productivity and fisheries management of the Northeast shelf ecosystem, p. 107-124. *In*: Sherman, K., Alexander, L., and Gold, D. (eds.). Food chains, yields, models and management of large marine ecosystems. Westview Press, San Francisco, CA.

SILVER HAKE TABLES

Table A1. Silver hake landings (mt) by stock area during 1955-2004 for foreign and domestic fishing fleets.

Year	Northern stock area			Southern stock area			North plus south stock areas		
	Foreign	Domestic	Total	Foreign	Domestic	Total	Foreign	Domestic	Foreign + domestic
1955		53,361	53,361		13,842	13,842	0	67,203	67,203
1956		42,150	42,150		14,871	14,871	0	57,021	57,021
1957		62,750	62,750		17,153	17,153	0	79,903	79,903
1958		49,903	49,903		13,473	13,473	0	63,376	63,376
1959		50,608	50,608		17,112	17,112	0	67,720	67,720
1960		45,543	45,543		9,206	9,206	0	54,749	54,749
1961		39,688	39,688		13,209	13,209	0	52,897	52,897
1962	36,575	42,427	79,002	5,325	13,408	18,733	41,900	55,835	97,735
1963	37,525	36,399	73,924	74,023	19,359	93,382	111,548	55,758	167,306
1964	57,240	37,222	94,462	127,036	26,518	153,554	184,276	63,740	248,016
1965	15,793	29,449	45,242	283,366	23,765	307,131	299,159	53,214	352,373
1966	14,239	33,477	47,716	200,058	11,212	211,270	214,297	44,689	258,986
1967	6,882	26,489	33,371	81,749	9,500	91,249	88,631	35,989	124,620
1968	10,506	30,873	41,379	49,422	9,074	58,496	59,928	39,947	99,875
1969	8,047	15,917	23,964	67,396	8,165	75,561	75,443	24,082	99,525
1970	12,305	15,223	27,528	20,633	6,879	27,512	32,938	22,102	55,040
1971	25,243	11,158	36,401	66,344	5,546	71,890	91,587	16,704	108,291
1972	18,784	6,440	25,224	88,381	5,973	94,354	107,165	12,413	119,578
1973	18,086	13,997	32,083	97,989	6,604	104,593	116,075	20,601	136,676
1974	13,775	6,905	20,680	102,112	7,751	109,863	115,887	14,656	130,543
1975	27,308	12,566	39,874	65,812	8,441	74,253	93,120	21,007	114,127
1976	151	13,483	13,634	58,307	10,434	68,741	58,458	23,917	82,375
1977	2	12,455	12,457	47,850	11,458	59,308	47,852	23,913	71,765
1978		12,609	12,609	14,353	12,779	27,132	14,353	25,388	39,741
1979		3,415	3,415	4,877	13,498	18,375	4,877	16,913	21,790
1980		4,730	4,730	1,698	11,848	13,546	1,698	16,578	18,276
1981		4,416	4,416	3,043	11,783	14,826	3,043	16,199	19,242
1982		4,656	4,656	2,397	12,164	14,561	2,397	16,820	19,217
1983		5,310	5,310	620	11,520	12,140	620	16,830	17,450
1984		8,289	8,289	412	12,731	13,143	412	21,020	21,432
1985		8,297	8,297	1,321	11,843	13,164	1,321	20,140	21,461
1986		8,502	8,502	550	9,573	10,123	550	18,075	18,625
1987		5,658	5,658	2	10,121	10,123	2	15,779	15,781
1988		6,767	6,767		9,195	9,195	0	15,962	15,962
1989		4,646	4,646		13,169	13,169	0	17,815	17,815
1990		6,379	6,379		13,615	13,615	0	19,994	19,994
1991		6,053	6,053		10,093	10,093	0	16,146	16,146
1992		5,302	5,302		10,288	10,288	0	15,590	15,590
1993		4,360	4,360		12,912	12,912	0	17,272	17,272
1994		5,724	5,724		10,334	10,334	0	16,058	16,058
1995		3,033	3,033		11,694	11,694	0	14,727	14,727
1996		3,200	3,200		12,999	12,999	0	16,199	16,199
1997		2,591	2,591		12,994	12,994	0	15,585	15,585
1998		2,258	2,258		12,701	12,701	0	14,959	14,959
1999		4,042	4,042		9,970	9,970	0	14,012	14,012

2000	2,418	2,418	9,760	9,760	0	12,178	12,178
2001	3,446	3,446	8,694	8,694	0	12,140	12,140
2002	2,839	2,839	5,153	5,153	0	7,992	7,992
2003	1,727	1,727	6,916	6,916	0	8,643	8,643
2004	557	557	7,889	7,889	0	8,445	8,445

Table A1. (cont.)

Table A2. Proportion of total landings (mt) by market category and gear group during 1995-2004.

Market Category	Gillnets	Hook&Line	OtherGear	OtterTrawl	UnkGear	Grand Total
5090 (Round)	0.15%	0.04%	0.32%	65.84%	1.56%	67.91%
5091 (King round)	0.06%	0.00%	0.05%	6.36%	0.06%	6.54%
5092 (Small round)	0.18%	0.02%	0.04%	22.73%	0.10%	23.07%
5093 (Dressed)	0.01%	0.00%	0.95%	0.02%	0.00%	0.97%
5094 (Juvenile)	0.00%	0.00%	0.00%	1.09%	0.19%	1.28%
5095 (Large round)	0.00%	0.00%	0.09%	0.12%	0.02%	0.23%
Grand Total	0.39%	0.06%	1.45%	96.16%	1.93%	100.00%

Table A3. Sampling intensity (length measurements / mt landed) for commercial landings during 1995-2004.

Market Category	Landings (mt)	Gear Groups					All
		Gillnets	Hook&Line	OtherGear	OtterTrawl	UnkGear	
5090 (Round)	85,316	3.91	0	0.34	0.48	0	0.47
5091 (King round)	8,220	0.50	0	0	1.63	0	1.59
5092 (Small round)	28,981	0	9.26	0	0.48	0	0.48
5093 (Dressed)	1,219	0	0	0	0	0	0
5094 (Juvenile)	1,608	No landings	0	0	0.47	0	0.40
5095 (Large round)	289	No landings	0	0	0	0	0
All	125,633	1.54	2.61	0.07	0.55	0	0.54

Table A4. Names, database codes (NESPP3) and groups for species used to estimate discard for silver hake.

Species Group	Species Code (NESPP3)	Species Name	Species Group	Species Code (NESPP3)	Species Name
Monkfish	12	ANGLER	Crabs/Shrimps	711	CRAB
Squid/Butterfish	51	BUTTERFISH	Crabs/Shrimps	712	CRAB
Squid/Butterfish	801	SQUID (LOLIGO)	Crabs/Shrimps	713	CRAB
Squid/Butterfish	802	SQUID (ILLEX)	Crabs/Shrimps	714	CRAB
Squid/Butterfish	803	SQUIDS (NS)	Crabs/Shrimps	715	CRAB
Principal Grndfsh	81	COD	Crabs/Shrimps	718	CRAB
Principal Grndfsh	147	HADDOCK	Crabs/Shrimps	724	CRAB
Principal Grndfsh	153	HAKE	Crabs/Shrimps	727	LOBSTER
Principal Grndfsh	155	HAKE MIX RED & WHITE	Crabs/Shrimps	735	SHRIMP (NK)
Principal Grndfsh	240	REDFISH	Crabs/Shrimps	736	SHRIMP (PANDALID)
Principal Grndfsh	269	POLLOCK	Crabs/Shrimps	737	SHRIMP (MANTIS)
Herring/Shad/Other/Pelagics	112	HERRING	Crabs/Shrimps	738	SHRIMP (PENAEID)
Herring/Shad/Other/Pelagics	347	SHAD	Mollusks	748	QUAHOG
Flatfish	120	FLOUNDER	Mollusks	754	QUAHOG
Flatfish	122	FLOUNDER	Mollusks	764	CLAM NK
Flatfish	123	FLOUNDER	Mollusks	769	CLAM
Flatfish	124	FLOUNDER	Mollusks	775	CONCHS
Flatfish	125	FLOUNDER	Mollusks	776	WHELK
Flatfish	126	FLOUNDERS (NK)	Mollusks	777	WHELK
Flatfish	128	HOGCHOCKER	Mollusks	781	MUSSELS
Flatfish	158	HALIBUT	Mollusks	786	OCTOPUS
Flatfish	159	HALIBUT	Mollusks	799	SCALLOP
Fluke/Fourspot	121	FLOUNDER	Scallops	800	SCALLOP
Fluke/Fourspot	127	FLOUNDER	Urchins/Cumcumbers/Shellfish	805	SEA URCHINS
Hakes+OceanPout	152	HAKE	Urchins/Cumcumbers/Shellfish	806	SEA CUCUMBERS
Hakes+OceanPout	250	POUT	Urchins/Cumcumbers/Shellfish	828	STARFISH
Hakes+OceanPout	508	HAKE	Other Species	1	ALEWIFE
Hakes+OceanPout	509	HAKE	Other Species	23	BLUEFISH
Atlantic herring	167	HERRING (NK)	Other Species	24	SQUIRRELFISH
Atlantic herring	168	HERRING	Other Species	33	BONITO
Atlantic mackerel	212	MACKEREL	Other Species	87	CREVALLE
Menhaden	221	MENHADEN	Other Species	90	CROAKER
Scup/Seabass	329	SCUP	Other Species	93	CUNNER
Scup/Seabass	335	SEA BASS	Other Species	96	CUSK
Dogfishes	350	DOGFISH (NK)	Other Species	106	DRUM
Dogfishes	351	DOGFISH SMOOTH	Other Species	107	DRUM
Dogfishes	352	DOGFISH SPINY	Other Species	115	EEL
Other sharks	353	SHARK	Other Species	116	EEL
Other sharks	357	SHARK	Other Species	117	EEL
Other sharks	359	SHARK	Other Species	130	FLOUNDER
Other sharks	478	SHARK	Other Species	133	GARFISH
Other sharks	482	SHARK	Other Species	134	GIZZARD SHAD
Skates/Rays	365	SKATES	Other Species	150	HAGFISH
Skates/Rays	366	SKATE	Other Species	165	HARVEST FISH
Skates/Rays	367	SKATE	Other Species	173	SHAD
Skates/Rays	368	SKATE	Other Species	188	JOHN DORY
Skates/Rays	369	SKATE	Other Species	189	DORY
Skates/Rays	370	SKATE	Other Species	194	MACKEREL
Skates/Rays	372	SKATE	Other Species	197	WHITING
Striped Bass	418	BASS	Other Species	210	LUMPFISH
Large Pelagics	466	TUNA	Other Species	213	BLUE RUNNER
Large Pelagics	468	TUNA	Other Species	215	MACKEREL
Crabs/Shrimps	700	CRAB	Other Species	234	MULLET
Crabs/Shrimps	710	CRAB	Other Species	235	STRIPED MULLET

Table A4 (cont.)

Species Group	Species Code (NESPP3)	Species Name
Other Species	242	ROSEFISH
Other Species	258	PIGFISH
Other Species	267	PINFISH
Other Species	268	LADYFISH
Other Species	272	POMPANO
Other Species	326	SCULPINS
Other Species	327	SEA RAVEN
Other Species	333	SEA BASS
Other Species	334	SEATROUT
Other Species	340	SEA ROBIN
Other Species	341	SEA ROBINS
Other Species	342	SEA ROBIN
Other Species	343	SEA ROBIN
Other Species	344	WEAKFISH
Other Species	345	WEAKFISH
Other Species	356	SHEEPSHEAD
Other Species	364	SKATE
Other Species	371	SMELT
Other Species	381	SPADEFISH
Other Species	384	MACKEREL
Other Species	406	SPOT
Other Species	429	PUFFER
Other Species	430	PUFFER
Other Species	438	TAUTOG
Other Species	444	TILEFISH
Other Species	446	TILEFISH
Other Species	447	TILEFISH (NK)
Other Species	456	TRIGGERFISH
Other Species	512	WOLFFISHES
Other Species	526	OTHER FISH
Other Species	660	OTHER FISH
Other Species	661	OTHER FISH
Other Species	662	OTHER FISH
Other Species	664	OTHER FISH
Other Species	667	OTHER FISH
Other Species	668	OTHER FISH
Other Species	678	OTHER FISH
Other Species	679	OTHER FISH
Other Species	681	OTHER FISH
Other Species	686	OTHER FISH
Other Species	687	OTHER FISH
Other Species	688	OTHER FISH
Other Species	733	SHRIMP ROYAL RED
Other Species	778	WHELK
Other Species	796	SCALLOPS NK
Other Species	804	MOLLUSKS NK

Table A5. Names, database codes (NEGEAR) and groups for fishing gear used to estimate discard for silver hake. “Total Hail Weight” is the total hail weight for landings by the gear group in observer data for 2001-2004 (a measure of potential importance for each gear group).

Gear Group	Gear Code (NEGEAR)	Gear Name	Total Hail Weight (mt)
Dredges	132	DREDGE, SCALLOP,SEA	8,172
Gill/set nets	100	GILL NET, FIXED OR ANCHORED,SINK, OTHER/NK SPECIES	2,999
Gill/set nets	105	GILL NET, ANCHORED-FLOATING, FISH	13
Gill/set nets	116	GILL NET, DRIFT-FLOATING, FISH	50
Hook & line	10	LONGLINE, BOTTOM	265
Shrimp trawls	58	TRAWL,OTTER,BOTTOM,SHRIMP	18
Trawls	50	TRAWL,OTTER,BOTTOM,FISH	14,823
Trawls	52	TRAWL,OTTER,BOTTOM,SCALLOP	39
Other/unknown gear	20	HANDLINE	0.21
Other/unknown gear	60	TROLL LINE, OTHER/NK SPECIES	0.01
Other/unknown gear	117	GILL NET, DRIFT-SINK, FISH	554
Other/unknown gear	120	PURSE SEINE, OTHER/NK SPECIES	217
Other/unknown gear	121	PURSE SEINE, HERRING	2,324
Other/unknown gear	170	TRAWL,OTTER,MIDWATER PAIRED	15,685
Other/unknown gear	181	POTS + TRAPS,FISH	2
Other/unknown gear	200	POT/TRAP, LOBSTER OFFSH NK	0.19
Other/unknown gear	360	SCOTTISH SEINE	25
Other/unknown gear	370	TRAWL,OTTER,MIDWATER	2,848

Table A6. Number of trips with observers during 2001-2004 used to estimate discard rates and discard for silver hake, by primary species group and gear group.

Species Group	Gear Groups								Total
	Dredges	Gill/set nets	Hook & line	Shrimp trawls	Bottom Trawls	Purse seines	Midwater trawls	Other/ unknown gear	
Atlantic herring	0	5	0	0	12	27	27	82	153
Atlantic mackerel	0	10	0	0	8	0	2	15	35
Bonito	0	3	0	0	0	0	0	1	4
Crabs/Shrimps	0	6	0	31	66	0	0	5	108
Dogfishes	0	242	2	0	16	0	0	0	260
Flatfish	0	229	0	0	722	0	0	13	964
Fluke/Fourspot	0	54	1	0	358	0	0	4	417
Hakes+OceanPout	0	2	0	0	93	0	3	6	104
Herring/Shad/Other	0	16	0	0	3	0	0	0	19
Large Pelagics	0	9	1	0	0	0	0	0	10
Menhaden	0	75	0	0	0	2	0	0	77
Mollusks	0	0	0	0	1	0	0	0	1
Monkfish	0	865	0	0	147	0	0	0	1012
Other Species	0	928	3	0	51	0	0	1	983
Principal Grndfs	0	1595	146	0	559	0	0	5	2305
Scallops	285	0	0	0	37	0	0	0	322
Scup/Seabass	0	1	0	0	67	0	0	9	77
Skates/Rays	0	218	0	0	102	0	0	0	320
Squid/ButterFish	0	5	0	0	233	0	12	0	250
Striped Bass	0	90	3	0	5	0	0	0	98
Total	285	4353	156	31	2480	29	44	141	7519

Table A7. Discard to kept (DK) ratios and mean annual discard (mt y⁻¹) for silver hake from ratio estimators, by primary species group and primary gear group, based on observer data for 2001-2004. Results are sorted in descending order by DK ratio. Primary species group and gear group combinations not shown had DK ratios < 0.00001. The CV for the DK ratio is the same as the CV for discard because landings were assumed measured without error. The "Assumed stock area" for cases with mean annual discard > 70 mt per year is the principle silver hake stock area for landings and discards based on the primary geographical location of the fishery. Landings for crabs/shrimps in shrimp trawls also include landings for crabs/shrimps in other/unknown gear.

Species Group	Gear Group	N trips	DK ratio	CV	Mean 2001 - 2004 landings (mt y ⁻¹)	Mean discard 2001-2004 (mt y ⁻¹)	Assumed stock area
Hakes+OceanPout	Other/unknown gear	6	0.24082	1.46	297	72	South
Hakes+OceanPout	Bottom trawls	93	0.12455	0.20	9,822	1,223	South
Squid/ButterFish	Bottom trawls	233	0.02423	0.24	24,673	598	South
Crabs/Shrimps	Shrimp trawls	31	0.02150	0.32	73,479	1,580	North
Dogfishes	Bottom trawls	16	0.00946	0.39	232	2.2	
Monkfish	Bottom trawls	147	0.00830	0.14	12,672	105	South
Principal Grndfsh	Other/unknown gear	5	0.00458	0.91	415	1.9	
Flatfish	Bottom trawls	722	0.00437	0.15	17,133	75	
Principal Grndfsh	Bottom trawls	559	0.00434	0.14	19,112	83	
Flatfish	Other/unknown gear	13	0.00406	0.84	651	2.6	
Atlantic herring	Bottom trawls	12	0.00371	1.04	7,678	28	
Scup/Seabass	Bottom trawls	67	0.00189	0.41	2,775	5.2	
Flatfish	Gill/set nets	229	0.00166	0.41	648	1.1	
Fluke/Fourspot	Bottom trawls	358	0.00085	0.28	5,831	5.0	
Squid/ButterFish	Midwater trawls	12	0.00080	0.90	176	0.1	
Principal Grndfsh	Gill/set nets	1595	0.00045	0.13	5,892	2.7	
Scallops	Bottom trawls	37	0.00028	0.73	14,540	4.1	
Atlantic herring	Other/unknown gear	82	0.00020	0.63	38,263	7.7	
Skates/Rays	Bottom trawls	102	0.00020	0.35	9,897	2.0	
Dogfishes	Gill/set nets	242	0.00011	0.27	1,156	0.1	
Other Species	Bottom trawls	51	0.00011	0.81	5,612	0.6	
Scallops	Dredges	285	0.00010	0.37	191,675	19.2	
Monkfish	Gill/set nets	865	0.00006	0.25	8,428	0.5	
Atlantic herring	Midwater trawls	27	0.00005	0.73	26,953	1.3	
Skates/Rays	Gill/set nets	218	0.00003	0.72	3,292	0.1	
Crabs/Shrimps	Bottom trawls	66	0.00002	0.60	1,057	0.0	
All	All	6073		0.17	482,358	3,820	na

[illegible]

		Year of Survey																																															
Stratum	Stock	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	00	01	02	03	04						
3010	S										2	2		2	1	1	1	1		1	1	1	1	1	1	1	2																						
3020	S										2	2	2	2	2	1	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	1	2	2	2	2	2	2	2	2			
3030	S										2	2		2	1	1	1	1	1				2	2	2	1	1		1	1	1	1	1		1	1	1	1	1	1	1	1		1					
3040	S										2	2	2	2	2	2	2	2	2	2	2	3	3	2	2	2	2	1	3	2	2	2	2	3	2	2	2	2	2	2	2	2	2	2	3	2			
3050	S										2	2	2	2	2	2	2	2	2	2	2	2	2	1	2	2	2	3	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2			
3060	S										2	2		1		1		1						1	1						1	1	1	1	1	1	1	1	1	1	1	1		1	1				
3070	S										2	2	1	3	3	2	3	2	2	3	2	3	3	2	2	2	2	1	3	3	2	2	2	2	2	2	2	2	2	2	2	2	2	3	2	2			
3080	S										2	2	4	2	2	2	2	2	2	2	3	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2			
3090	S										2	2		2	1	1	1	1	1	1	1		1	1	1					1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1			
3100	S										2	4	2	2	2	2	1	2	2	2	3	2	2	2	2	2	2	2	3	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2		
3110	S										3	5	3	3	2	2	2	3	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2		
3120	S										5	6			1	1	1	1	1			1	1	1	1				1		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1		
3130	S										4	6	2	3	2	2	2	2	2	2	3	2	2	2	2	2	2	1	2	1	2	1	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	
3140	S										5	14	4	3	2	2	2	2	1	2	2	2	2	2	2	2	2	2	2	2	2	4	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2		
3150	S										3																																						

Table A10. Number of successful random tows (SHG code <= 136) for offshore strata during spring NEFSC bottom trawl surveys during 1968-2005. Cells with zero tows are black. Strata are assigned to stock ("S" for southern and "N" for northern).

		Year of Survey																																													
Stratum	Stock	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	00	01	02	03	04	05			
1010	S						6	7	7	8	7	16	7	6	8	7	8	7	7	8	7	7	7	7	7	7	7	7	7	7	7	7	7	7	8	7	7	7	7	7	7	7	6	7	7		
1020	S						5	7	9	7	8	14	6	8	7	7	8	7	7	7	7	7	7	5	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	6	7	7		
1030	S						4	3	8	3	5	6	3	3	3	3	2	3	3	2	3	3	3	3	3	3	4	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2		
1040	S						4	3	3	3	4	3	3	3	2	3	1	3	2	1	3	3	3	2	3	3	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1		
1050	S						4	5	5	5	5	10	4	6	5	5	7	10	17	3	5	4	4	5	5	5	6	5	5	5	4	4	5	5	4	5	5	5	5	5	5	5	5	5	5	5	
1060	S						6	8	9	11	9	16	8	9	9	8	10	8	28	8	8	8	9	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	
1070	S						4	3	4	3	4	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2		
1080	S						3	3	3	3	3	3	2	3	2	4	3	2	3	3	2	3	3	3	3	3	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1		
1090	S						4	5	5	6	5	5	4	5	5	6	5	15	18	5	5	5	5	6	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	
1100	S						6	8	10	9	8	8	8	7	10	9	8	8	20	8	8	8	7	7	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8
1110	S						4	3	4	3	4	3	3	3	3	3	3	3	3	3	3	3	3	3	4	3	3	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	
1120	S						3	3	3	3	4	3	3	3	3	3	2	3	2	3	3	2	3	2	2	3	1	1	1	1	1	1				1	1		1	1	1	1	1	1	1		
1130	S						7	9	9	13	9	9	8	9	9	9	9	18	8	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	
1140	S						4	4	4	4	4	4	3	4	4	5	5	4	4	4	4	4	4	4	5	4	4	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	
1150	S						4	3	3	3	3	3	3	3	3	3	3	3	3	3	3	2	3	3	2	3	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1		
1160	S						9	14	10	20	13	10	10	10	10	9	12	20	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	9	10	10	10	10	10	10	10	10	10	10	
1170	S						4	4	4	7	4	4	3	4	3	4	4	4	5	4	4	4	4	4	4	4	4	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	
1180	S						3	3	2	3	3	3	3	2	2	3	3	2		3	2	3	2	3	3	1	1		1	1	1	1	1	1	1	2	1	1	1	1	1	1	1	1	1	1	
1190	S						8	8	8	14	9	9	9	9	9	8	9	18	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	
1200	N						6	6	5	9	6	6	6	6	6	6	6	12	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	
1210	N						4	4	4	9	4	4	5	4	4	4	4	8	4	4	4	4	4	3	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	3	4	4	4	
1220	N						4	4	4	6	5	4	2	4	4	4	4	5	8	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	
1230	N						6	5	5	7	5	5	5	5	6	6	6	10	5	4	5	5	5	4	5	5	4	4	4	5	5	4	6	4	4	4	4	5	5	5	5	5	5	5	5	5	
1240	N						6	6	6	10	7	6	6	6	6	7	9	12	6	6	6	6	6	5	6	6	6	6	6	6	6	6	6	6	6	6	4	6	9	6	6	6	6	6	6		
1250	N						4	4	4	4	4	3	4	3	3	4	7	2	4	5	3	4	2	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	
1260	N						3	5	5	5	5	5	15	14	14	5	9	5	6	7	5	4	5	5	3	5	5	5	4	5	5	5	4	5	5	5	5	5	8	5	5	5	5	5	5	5	
1270	N						4	4	4	5	4	2	4	3	3	4	5	8	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	5	4	4	6	4	4	4	4	4	4	5	
1280	N						7	7	7	7	7	7	6	7	8	9	8	7	7	7	7	7	7	6	7	7	7	7	7	7	7	7	7	7	6	7	7	7	11	7	7	7	7	7	7	7	
1290	N						8	8	9	8	9	7	5	6	8	8	10	8	8	8	8	8	7	8	8	9	8	8	8	8	8	8	8	8	8	8	8	8	8	9	8	7	8	8	8	8	
1300	N						3	3	3	3	3	2	3	3	3	3	4	3	3	2	3	3	3	3	3	3	3	3	2	3	3	3	2	3	3	3	3	3	3	3	3	3	3	3	3	3	
1310	N						6	7	11	10	7	7	6	7	7	7	8	6	7	5	6	7	5	6	4	6																					
1320	N						5	5	5	7	5	4	4	4	5	5	5	5	5	4	3	5	3	5	3	5	5																				
1330	N						4	2	5	4	4	4			4	4	5	4	4	3	4	3	3	3	3	4	3		4	3		3	3	4	2	4	4			3	4	3	4	3	4		
1340	N						5	5	6	7	6	5	5	6	4	6	8	6	6	5	5	6	6	6	6	5	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	
1350	N						3	3	4	2	4	5	4		2	4	5	4	2	2	4	3	1	3	3																						
1351	S																																														
1360	S						8	8	8	9	9	8	8	7	9	9	10	8	8	7	8	8	7	6	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	
1370	S						5	5	5	5	5	4	5	4	5	5	5	5	5	5	5	5	5	5	5	5	5	4	5	5	5	5	5	5	5	5	5	8	5	5	5	5	5	5	5	5	
1380	S																																														

		Year of Survey																																															
Stratum	Stock	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	00	01	02	03	04	05					
3010	S												2	2		1	1	1		2	1	1	1	1	1	1																							
3020	S												2	2	1	1	2	3	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	
3030	S												2	2	1	1		1	1	2	1			2	1							1	1	1	1			1	1	1			1	1	1	1	1		
3040	S												2	2		2	2	2	2	4	2	3	2	1	3	2	2	2	2	2	3	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	
3050	S												2	2		2	3	2	2	4	2	2	1	3	2	3	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	
3060	S												2		1	1		1				1			1						1	1		1	1	1	1	1	1	1	1	1	1	1		1			
3070	S												2	4	1	2	2	2	3	3	2	3	2	3	3	1	2	2	2	2	2	2	3	2	2	2	2	2	2	2	2	2	2	3	2	2	2	2	
3080	S												2	2	3	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	3	2	2	2	2	2	2	2	2	2	2	2	2	
3090	S												3	2		1		1	1	1	1	1	1	1	1	1	1				1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1		
3100	S												3	3	3	2	2	3	2	2	2	2	2	2	2	1	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	
3110	S												3	9	4	2	2	3	2	1	2	2	2	2	2	3	2	2	2	2	2	2	2	2	3	2	2	2	2	2	2	2	2	2	2	2	2	2	
3120	S												5	1	1	1	1	1	1	1	1	1									1			1	1	1		1	1	1	1	1	1	1	1	1	1		
3130	S												9	4	1	2	2	1	1	2	2	2	2	2	2	1	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	
3140	S												23	6	3	2	2	1	2	2	2	2	2	3	3	3	2	2	2	2	2	2	2	2	2	2	3	2	2	1	2	2	2	2	2	2	2	2	
3150	S																																																

Table A12. Number of successful random tows (SHG code <= 136) for offshore strata covered by winter NEFSC bottom trawl surveys during 1992-2005. Cells with zero tows are black. Strata are assigned to stock ("S" for southern and "N" for northern). Inshore strata and the northern stock area are not sampled in the winter survey.

STRATUM	Stock	Year of Survey													
		92	93	94	95	96	97	98	99	00	01	02	03	04	05
1010	S	9	8	6	8	8	7	8	8	8	8	8	4	6	5
1020	S	7	7	5	7	8	7	7	7	8	8	8	4	7	5
1030	S	3	2	2	2	3	2	3	3	4	4	4	2	4	3
1040	S				1		1		1	1	2	2	2	1	1
1050	S	7	4	3	5	5	5	4	5	5	7	7	4	4	3
1060	S	9	9	5	9	10	9	9	8	10	12	11	5	11	7
1070	S	2	3	1	2	2	2	3	3	4	4	4	2	4	3
1080	S				1		1	1	1		2	2	1	2	1
1090	S	5	3	4	5	4	6	5	5	3	7	5	3	5	4
1100	S	6	8	8	8	10	8	8	9	7	12	12	6	10	7
1110	S	2	2	2	2	3	2	3	3	4	4	4	2	4	3
1120	S						1	1	1		2	2	2	1	1
1130	S	7	9	7	9	7	9	9	9	4	9	8		4	2
1140	S	1	3	2	3	4	3	4	4	2	4	4		4	
1150	S						1	1	1		2			1	
1160	S	5		1	9	2	5	10	8		6				
1170	S				1	2	1	3	3		2				
1180	S										1				
1190	S	5		4	5				4						
1610	S	4	5	3	4	4	4	4	4	5	6	7	7	7	6
1620	S	1	2	1	2	2	2	2	2	3	2	5	3	3	1
1630	S	1		2	1	2	2	3	3	3	2	3	3	4	2
1640	S							1	1	1	2		2	1	
1650	S	7	9	5	8	9	8	9	9	10	12	12	10	10	8
1660	S	2	3	1	4	4	3	3	3	4	4	4	3	4	3
1670	S	2	1	2	2	3	3	3	3	4	4	4	4	4	3
1680	S							1	1	1	2	2	2	2	1
1690	S	8	10	5	8	9	8	8	8	9	9	9	6	6	7
1700	S	4	5	4	4	5	4	4	4	5	5	5	4	5	4
1710	S	2	2	1	2	3	2	3	3	4	4	4	4	4	3
1720	S						1	1	1	1	3	1	2	2	2
1730	S	5	6	3	5	6	5	5	5	3	5	5	3	4	4
1740	S	4	5	4	4	5	4	4	4	5	5	5	3	5	5
1750	S	2	2	1	2	3	2	3	3	4	5	5	4	4	3
1760	S		1				1	1	1	1	1	1	2	2	2

Table A13. Strata for silver hake survey data used for environmental and trend analyses. Offshore and inshore bottom trawl survey strata in the table were consistently sampled (at least one during each year) in the fall survey during 1979-2004, spring survey during 1979-2005 and winter survey during 1992-2005, by stock area for silver hake. The winter survey does not sample inshore strata or the northern stock area.

Survey	Stock	Offshore	Inshore	N offshore	N inshore	N total
Winter	Southern	1010-1030, 1050-1070, 1090-1110, 1610-1620, 1650-1670, 1690-1710, 1730-1750	NA	20	NA	20
Spring	Northern	1020-1300,1340	None	12	0	12
Spring	Southern	1010-1110, 1130-1170, 1190, 1360-1400	3020, 3040-3050, 3070-3080, 3100- 3110, 3130-3140, 3160-3170, 3190- 3200, 3220-3230, 3250-3260, 3280- 3290, 3310-3320, 3340-3350, 3370- 3380, 3400-3410, 3430-3440, 3460, 3520	17	31	48
Fall	Northern	1200-1300,1330- 1340, 1360-1400	3610	18	1	19
Fall	Southern	1010-1190, 1610-1620, 1650-1670, 1690-1710, 0173-0176	3020, 3040-3050, 3070-3080, 3100- 3110, 3130-3140, 3160-3170, 3190- 3200, 3220-3230, 3250-3260, 3280- 3290, 3310-3320, 3340-3350, 3370- 3380, 3400-3410, 3430-3460, 3550	31	32	63

Table A14. Final generalized additive models (GAMs) for probability of occurrence of silver hake in winter, spring and fall surveys. Final models were selected by a step-wise procedure based on the AIC statistic. Variables included in final models were either loess, quadratic or linear terms. Blank cells indicate variables that were not statistically significant based on AIC. Temperatures, depths and time at highest probability of a positive tow (PPT) were identified subjectively by looking at fitted lines in logit-scale partial residual plots. Time at highest PPT is labeled "noon" for predicted curves that were concave down and "midnight" for curves that were concave up.

Survey	Stock	Lengths	Length Group Label in Plots	Bottom Temperature (T)	Depth (D)	Time of Day (L)	Temperature range highest PPT (°C)	Depth range highest PPT (m)	Time at highest PPT
Fall	Northern	1.0 - 5.9	2.5	loess	loess	quadratic	> 15	< 150	noon
		6.0 - 10.9	7.5	loess		quadratic	> 15		noon
		11.0 - 15.9	12.5	quadratic		loess	8		noon
		16.0 - 20.9	17.5	quadratic	loess		8	< 150	
		21.0 - 25.9	22.5	loess	loess		11	190	
		26+	27.5	loess	loess		< 15	> 200	
	Southern	1.0 - 5.9	2.5	loess	loess	loess	10 - 17	< 150	midnight
		6.0 - 10.9	7.5	loess	loess	loess	> 15	< 150	midnight
		11.0 - 15.9	12.5	loess	loess	loess	> 15	not clear	not clear
		16.0 - 20.9	17.5	quadratic	loess	linear	10	< 150	not clear
		21.0 - 25.9	22.5	loess	loess	loess	< 15	< 150	not clear
		26+	27.5	quadratic	loess		14	> 90	not clear
	Both	1.0 - 5.9	2.5	loess	loess	loess	15	< 100	midnight
		6.0 - 10.9	7.5	loess	loess	loess	> 15	< 100	midnight
		11.0 - 15.9	12.5	loess	loess	quadratic	< 10	> 100	noon
		16.0 - 20.9	17.5	loess	quadratic		< 10	150	
		21.0 - 25.9	22.5	loess	loess	loess	< 10	200	not clear
		26+	27.5	loess	loess		< 15	> 100	not clear
Spring	Northern	1.0 - 5.9	2.5	NA	NA	NA	NA	NA	NA
		6.0 - 10.9	7.5		loess	loess		100 - 250	midnight
		11.0 - 15.9	12.5	loess	loess	loess	< 9	200	midnight
		16.0 - 20.9	17.5	quadratic	loess	quadratic	6	200	midnight
		21.0 - 25.9	22.5	loess	quadratic		< 10	250	
		26+	27.5	quadratic	quadratic		< 6	300	
	Southern	1.0 - 5.9	2.5		loess	loess		< 200	midnight
		6.0 - 10.9	7.5	quadratic	loess	loess	9	< 100	midnight
		11.0 - 15.9	12.5		loess	quadratic		< 100	midnight
		16.0 - 20.9	17.5	loess	loess	loess	6	< 250	midnight
		21.0 - 25.9	22.5	loess	loess		7	> 100	
		26+	27.5	quadratic	loess		not clear	not clear	
	Both	1.0 - 5.9	2.5	NA	NA	NA	NA	NA	NA
		6.0 - 10.9	7.5	quadratic	loess	loess	< 6	not clear	midnight
		11.0 - 15.9	12.5	loess	loess	loess	< 6	220	midnight
		16.0 - 20.9	17.5	loess	loess	quadratic	5	200	midnight
		21.0 - 25.9	22.5	quadratic	loess	loess	8	> 100	not clear
		26+	27.5	loess	loess	loess	> 8	> 80	not clear
Winter	Southern	1.0 - 5.9	2.5	loess	loess	quadratic	> 8	< 150	midnight
		6.0 - 10.9	7.5	loess	quadratic		< 8	150	
		11.0 - 15.9	12.5	loess	loess		< 8	> 150	
		16.0 - 20.9	17.5	loess	loess		5	> 100	
		21.0 - 25.9	22.5	loess	loess		6	> 100	
		26+	27.5	loess	loess		7	> 75	

Table A15. Final generalized additive models (GAMs) for catches of silver hake in winter, spring and fall survey tows where at least one silver hake was taken. Final models were selected by a step-wise procedure based on the AIC statistic. Variables included in final models were either loess, quadratic or linear terms. Blank cells indicate variables that were not statistically significant based on AIC. Temperatures, depths and time at highest density were identified subjectively by looking at fitted lines in log-scale partial residual plots. Time at highest density is labeled "noon" for predicted curves that were concave down and "midnight" for curves that were concave up.

Survey	Stock	Lengths	Length Group Label in Plots	Bottom Temperature (T)	Depth (D)	Time of Day (L)	Temperature range highest PPT (°C)	Depth range highest PPT (m)	Time at highest PPT
Fall	Northern	1.0 - 5.9	2.5	loess	loess	loess	10 - 17	< 100	midnight
		6.0 - 10.9	7.5	loess	loess	loess	10 - 17	< 100	midnight?
		11.0 - 15.9	12.5	quadratic	quadratic		12	100 - 200	
		16.0 - 20.9	17.5	loess	loess		10	100	
		21.0 - 25.9	22.5	loess	loess	loess	8	125 - 225	midnight
		26+	27.5	loess	loess	loess	8	200	midnight
	Southern	1.0 - 5.9	2.5	loess	loess	loess	10 - 16	< 100	midnight
		6.0 - 10.9	7.5	loess	loess	loess	10 - 18	< 100	midnight
		11.0 - 15.9	12.5	quadratic	quadratic		12	100 - 200	
		16.0 - 20.9	17.5	loess	loess		8 - 10	100 - 150	
		21.0 - 25.9	22.5	loess	loess	loess	9	150 - 250	midnight
		26+	27.5	loess	loess	loess	< 10	200	midnight
	Both	1.0 - 5.9	2.5	loess	loess	loess	8 - 17	< 100	midnight
		6.0 - 10.9	7.5	loess	loess	loess	10 - 17	< 100	midnight?
		11.0 - 15.9	12.5	quadratic	quadratic		12	125	
		16.0 - 20.9	17.5	loess	loess		7 - 10	100	
		21.0 - 25.9	22.5	loess	loess	loess	9	150 - 220	midnight
		26+	27.5	loess	loess	loess	< 10	> 200	midnight
Spring	Northern	1.0 - 5.9	2.5	NA	NA	NA	NA	NA	NA
		6.0 - 10.9	7.5	loess	loess	loess	< 8	< 100	midnight
		11.0 - 15.9	12.5	loess	loess	quadratic	< 8	200 - 250	midnight
		16.0 - 20.9	17.5	loess	loess	quadratic	8	> 150	midnight
		21.0 - 25.9	22.5	loess	loess		< 12	> 150	
		26+	27.5	loess	loess	quadratic	12	> 250	midnight
	Southern	1.0 - 5.9	2.5	NA	NA	NA	NA	NA	NA
		6.0 - 10.9	7.5	loess	loess	loess	< 10	< 100	midnight
		11.0 - 15.9	12.5	loess	loess	quadratic	< 10	200 - 250	midnight
		16.0 - 20.9	17.5	loess	loess	quadratic	6 - 8	> 150	midnight
		21.0 - 25.9	22.5	loess	loess		< 12	> 150	
		26+	27.5	loess	loess	quadratic	> 9	> 250	midnight
	Both	1.0 - 5.9	2.5	NA	NA	NA	NA	NA	NA
		6.0 - 10.9	7.5	loess	loess	loess	< 10	< 100	midnight
		11.0 - 15.9	12.5	loess	loess	quadratic	< 10	200 - 250	midnight
		16.0 - 20.9	17.5	loess	loess	quadratic	6 - 9	> 150	midnight
		21.0 - 25.9	22.5	loess	loess		< 12	> 150	
		26+	27.5	loess	loess	quadratic	> 9	> 250	midnight
Winter	Southern	1.0 - 5.9	2.5		linear	quadratic		< 100	midnight
		6.0 - 10.9	7.5	loess	loess	quadratic	< 6	< 100	midnight
		11.0 - 15.9	12.5	loess	loess	loess	< 6	70	not clear
		16.0 - 20.9	17.5	linear	quadratic		< 6	150 - 200	
		21.0 - 25.9	22.5	loess	loess		6 - 8	> 150	
		26+	27.5	loess	loess		8	> 150	

Table A16. Direction and statistical significance of estimated trends (linear regression models) in abundance weighted mean bottom temperatures, depths, latitudes and longitudes for silver hake taken during fall (1979-2004), spring (1978-2005) and winter (1992-2005) bottom trawl surveys. Symbols are "+" for increasing trends and "-" for decreasing trends. Variables with statistically significant regressions on time are identified by single ("*") for $0.1 \geq p\text{-values} > 0.05$ or double ("**") for $0.05 \geq p\text{-value}$ asterisks.

Lengths	Length Group Label in Plots	Fall			Spring			Winter		
		North	South	Both	North	South	Both	South		
Mean Bottom Temperature										
1.0 - 5.9	2.5					NA		NA		
6.0 - 10.9	7.5									
11.0 - 15.9	12.5			- **						
16.0 - 20.9	17.5									
21.0 - 25.9	22.5									
26+	27.5			- *						
Mean Depth										
1.0 - 5.9	2.5									
6.0 - 10.9	7.5	+ *		+ **						
11.0 - 15.9	12.5			+ *			+ *			
16.0 - 20.9	17.5	+ *								
21.0 - 25.9	22.5	+ *		+ *			+ **			+ *
26+	27.5			+ **				+ **		+ *
Mean Latitude										
1.0 - 5.9	2.5		+ *	+ *				NA		+ **
6.0 - 10.9	7.5	+ *		+ **						
11.0 - 15.9	12.5	+ *		+ **			+ **			
16.0 - 20.9	17.5					+ **	+ *	+ *		
21.0 - 25.9	22.5		+ **							
26+	27.5		+ **	+ **			+ **	+ **		
Mean Longitude										
1.0 - 5.9	2.5					NA		NA		- **
6.0 - 10.9	7.5			- *						
11.0 - 15.9	12.5					+ **				
16.0 - 20.9	17.5					+ *				
21.0 - 25.9	22.5		- **	- *						
26+	27.5		- **	- *			- **	- **		

Table A17. Number of relatively old individual fish in provisional survey age data for silver hake, by season and year. Duplicate records were removed manually.

Count of AGE		AGE							Grand Total
Season	year	8	9	10	11	12	13	14	
Fall	1973			3	2		1		6
	1975	2	1	1					4
	1976	1		1					2
	1977	3	2	1					6
	1978	14		1					15
	1979	6	4			1			11
	1980	21	3	2	1				27
	1981	23	2	1					26
	1982	6	3						9
	1983	1	2						3
	1984		1						1
	1985	1							1
	1989					1			1
Fall Total		78	18	10	3	2	1		112
Spring	1973	1	2	1		1		1	6
	1974	1	5		1			1	8
	1975		1						1
	1976	11	2	1					14
	1977	10	3	1					14
	1978	12		3	1			1	17
	1979	4	1						5
	1980	22	7	4		1			34
	1981	33	21		1				55
	1982	6	7	5		2			20
	1983	1	2	4					7
	1985	1	1						2
	1986	2							2
	1987	1	2						3
Spring Total		105	54	19	3	4		3	188
Grand Total		183	72	29	6	6	1	3	300

Table A18. Age reader precision experiment using 99 silver hake otoliths collected during the NEFSC spring 2004 bottom trawl survey. The sample of otoliths were aged a second time by the original technician without knowledge of the original ages.

Production Age	N	N agreed	% Agreement	Mean Age	SD
0					
1	9	9	100%	1.00	0.00
2	41	38	93%	2.07	0.26
3	23	21	91%	3.09	0.29
4	23	20	87%	3.96	0.37
5	3	3	100%	5.00	0.00
Total	99	91	92%		

Second age->

First age	0	1	2	3	4	5
0						
1		9				
2			38	3		
3				21	2	
4				2	20	1
5						3
	Total					99

Table A19. Age reader precision experiment using 99 silver hake otoliths collected during the NEFSC spring 2004 bottom trawl survey. The sample of otoliths were aged a second technician without knowledge of the ages estimated by the original technician.

Secondary reader reages a sample from 200402 cruise.

Production Age	N	N agreed	% Agreement	Mean Age	SD
0					
1	9	8	89%	1.11	0.33
2	41	39	95%	2.00	0.22
3	23	21	91%	2.95	0.21
4	23	7	30%	3.38	0.58
5	3	1	33%	5.67	0.58
Total	99	76	77%		

Second age ->

First age	0	1	2	3	4	5	6
0							
1		8	1				
2		1	39	1			
3			1	21			
4				16	7	1	
5						1	2
						Total	99

Table A20. Otoliths from a sample of 15 fish taken in NEFSC surveys during 1973-1982 and originally estimated to be at least age 7 y by several technicians were reaged by the current technician. New ages were all from sectioned otoliths. In some cases, original ages were from "baked" otoliths. All of the original age estimates were made prior to 1983.

ID	Cruise	Station	Length	Preparation for original age	Original age	Preparation for new age	New age
1	73-3	112	46	Section	7	Section	6
2	73-3	112	59	Section	7	Section	6
3	73-3	197	54	Section	10	Section	9
4	73-8	179	51	Section	10	Section	9
5	73-8	196	50	Section	10	Section	10
6	74-4	64	53	Section	9	Section	7
7	74-4	98	59	Section	9	Section	7
8	74-4	223	60	Section	9	Section	7
9	74-4	226	61	Section	14	Section	12
10	75-12	275	50	Baked	8	Section	5
11	75-12	321	63	Baked	6	Section	5
12	75-12	321	61	Baked	8	Section	6
13	79-12	616	68	Section	12	Section	11
14	82-02	348	64	Section	12	Section	11
15	82-02	420	66	Section	12	Section	9

Count of Cruise	New age									Grand Total
Original age	5	6	7	9	10	11	12	13	14	
5										
6	1									
7		2								
8	1	1								
9			3							
10				2	1					
12				1		2				
13							1			
14								1		
Grand Total	2	3	3	3	1	2	1	0	0	15

Table A21. Number of tows, mean catch per tow and mean densities of silver hake by stratum and transect canyon area for the NEFSC spring and Supplemental surveys during March, 2004-2005.

				NEFSC Survey (averages for all tows)						Supplemental Survey (averages for all tows)						Ratio NEFSC / Supplemental Density			
Year	Season	Canyon Area	NEFSC Stratum	N Random Stations	Bottom Temp. (°C)	Depth (m)	Catch (kg)	Swept Area (km ²)	Density (kg/km ²)	N Fixed Stations	Bottom Temp. (°C)	Depth (m)	Catch (kg)	Swept Area (km ²)	Density (kg/km ²)				
2004	Spring	Hudson	1020	7	3.5	69	0.274	0.041	6.7	3	5.5	89	202.4	0.269	739.7	0.0090			
2005	Spring	Hudson	1020	7	8.0	79	0.764	0.041	18.6	2	8.7	81	109.1	0.145	770.3	0.0242			
2004	Spring	Hudson	1030	2	7.7	16	2.268	0.041	55.3	1	10.7	144	691.6	0.293	2358.1	0.0235			
2005	Spring	Hudson	1030	2	10.6	81	0.286	0.041	7.0	2	11.5	127	141.0	0.130	1074.2	0.0065			
2004	Spring	Hudson	1040	1	11.3	216	0.553	0.041	13.5	3	10.6	224	394.2	0.294	1366.5	0.0099			
2005	Spring	Hudson	1040	1	6.5	289	26.142	0.041	637.8	3	10.6	227	1283.2	0.130	10078.4	0.0633			
2004	Spring	Baltimore	1700	4	6.7	73	0.057	0.041	1.4	3	2.3	91	18.5	0.246	77.1	0.0181			
2005	Spring	Baltimore	1700	4	7.8	67	0.112	0.041	2.7	2	9.9	82	35.0	0.144	238.2	0.0114			
2004	Spring	Baltimore	1710	4	6.7	73	0.057	0.041	1.4	2	5.7	162	36.6	0.270	132.0	0.0106			
2005	Spring	Baltimore	1710	4	7.8	67	0.112	0.041	2.7	3	10.9	149	143.7	0.149	950.7	0.0029			
2004	Spring	Baltimore	1720	1	5.8	375	0.000	0.041	0.0	2	10.1	244	257.1	0.265	968.1	0.0000			
2005	Spring	Baltimore	1720	1	6.8	355	1.042	0.041	25.4	2	8.3	256	2000.1	0.142	13932.3	0.0018			
													Average Hudson Canyon			0.0227			
													Median Hudson Canyon			0.0167			
38													28			Average Baltimore Canyon			0.0075
																Median Baltimore Canyon			0.0067
																Average 2004			0.0118
																Median 2004			0.0102
																Average 2005			0.0184
																Median 2005			0.0090

38

28

Table A22. NEFSC fall survey biomass index (delta mean kg/tow, all size groups), landings data, and exploitation index (landings / survey biomass index) for silver hake in the northern stock area. Survey data are for traditional NEFSC survey strata that have been consistently occupied since 1964. Three year averages show trends and are used in overfishing definitions.

Year	Fall Survey (delta mean kg/tow, all sizes)	CV	3-Year Average	Landings (L_t , 1000 mt)	Landings / Survey (all sizes)	3-Year Average
1964	4.42	0.20		94.46	21.40	
1965	6.48	0.28		45.24	6.99	
1966	4.12	0.19	5.00	47.72	11.57	13.32
1967	2.16	0.27	4.25	33.37	15.46	11.34
1968	2.05	0.27	2.78	41.38	20.20	15.75
1969	2.64	0.22	2.28	23.96	9.09	14.92
1970	3.03	0.26	2.57	27.53	9.07	12.79
1971	2.47	0.20	2.71	36.40	14.76	10.98
1972	6.09	0.16	3.86	25.22	4.15	9.33
1973	4.15	0.14	4.23	32.08	7.73	8.88
1974	3.76	0.28	4.67	20.68	5.49	5.79
1975	8.23	0.14	5.38	39.87	4.84	6.02
1976	12.63	0.22	8.21	13.63	1.08	3.81
1977	7.59	0.33	9.49	12.46	1.64	2.52
1978	7.07	0.14	9.10	12.61	1.78	1.50
1979	6.65	0.15	7.11	3.42	0.51	1.31
1980	6.66	0.18	6.79	4.73	0.71	1.00
1981	4.06	0.25	5.79	4.42	1.09	0.77
1982	5.45	0.56	5.39	4.66	0.85	0.88
1983	9.21	0.21	6.24	5.31	0.58	0.84
1984	3.62	0.22	6.09	8.29	2.29	1.24
1985	8.58	0.16	7.14	8.30	0.97	1.28
1986	14.19	0.16	8.80	8.50	0.60	1.28
1987	9.84	0.14	10.87	5.66	0.58	0.71
1988	6.31	0.20	10.11	6.77	1.07	0.75
1989	12.55	0.26	9.57	4.65	0.37	0.67
1990	15.25	0.25	11.37	6.38	0.42	0.62
1991	11.89	0.29	13.23	6.05	0.51	0.43
1992	14.25	0.38	13.79	5.30	0.37	0.43
1993	8.12	0.19	11.42	4.36	0.54	0.47
1994	6.93	0.14	9.76	5.72	0.83	0.58
1995	13.16	0.15	9.40	3.03	0.23	0.53
1996	7.89	0.16	9.32	3.20	0.41	0.49
1997	5.64	0.20	8.90	2.59	0.46	0.37
1998	21.97	0.31	11.83	2.26	0.10	0.32
1999	11.64	0.10	13.08	4.04	0.35	0.30
2000	13.79	0.13	15.80	2.42	0.18	0.21
2001	9.53	0.20	11.65	3.45	0.36	0.29
2002	8.00	0.11	10.44	2.84	0.35	0.30
2003	8.77	0.18	8.77	1.73	0.20	0.30
2004	3.40	0.22	6.72	0.56	0.16	0.24

Table A23. NEFSC fall survey biomass index (delta mean kg/tow, all size groups), landings data, and exploitation index (landings / survey biomass index) for silver hake in the southern stock area. Survey data are for traditional NEFSC survey strata that have been consistently occupied since 1964. Three year averages show trends and are used in overfishing definitions.

Year	Fall Survey (delta mean kg/tow, all sizes)	CV	3-Year Average	Landings (L_t , 1000 mt)	Landings / Survey (all sizes)	3-Year Average
1967	2.19	0.14	2.19	91.25	41.74	41.74
1968	2.69	0.13	2.44	58.50	21.72	31.73
1969	1.26	0.14	2.05	75.56	60.16	41.21
1970	1.33	0.13	1.76	27.51	20.65	34.18
1971	2.21	0.16	1.60	71.89	32.53	37.78
1972	2.00	0.22	1.85	94.35	47.18	33.45
1973	1.70	0.18	1.97	104.59	61.56	47.09
1974	0.86	0.21	1.52	109.86	127.45	78.73
1975	1.84	0.16	1.47	74.25	40.35	76.46
1976	2.06	0.14	1.59	68.74	33.34	67.05
1977	1.77	0.24	1.89	59.31	33.45	35.71
1978	2.93	0.24	2.26	27.13	9.26	25.35
1979	1.74	0.12	2.15	18.38	10.55	17.75
1980	2.12	0.35	2.26	13.55	6.38	8.73
1981	1.17	0.14	1.68	14.83	12.72	9.88
1982	1.65	0.20	1.65	14.56	8.82	9.31
1983	3.20	0.35	2.01	12.14	3.79	8.44
1984	1.56	0.30	2.14	13.14	8.44	7.02
1985	3.91	0.49	2.89	13.16	3.37	5.20
1986	1.39	0.17	2.28	10.12	7.29	6.37
1987	1.62	0.24	2.30	10.12	6.25	5.64
1988	1.83	0.23	1.61	9.20	5.02	6.19
1989	2.12	0.26	1.86	13.17	6.21	5.83
1990	1.65	0.17	1.87	13.62	8.28	6.50
1991	0.91	0.22	1.56	10.09	11.13	8.54
1992	0.98	0.14	1.18	10.29	10.52	9.97
1993	1.33	0.19	1.07	12.91	9.72	10.45
1994	0.80	0.16	1.04	10.33	12.93	11.06
1995	1.64	0.34	1.26	11.69	7.13	9.92
1996	0.43	0.16	0.96	13.00	30.16	16.74
1997	0.84	0.19	0.97	12.99	15.43	17.57
1998	0.62	0.18	0.63	12.70	20.49	22.03
1999	0.87	0.40	0.78	9.97	11.46	15.79
2000	0.72	0.22	0.74	9.76	13.50	15.15
2001	2.23	0.28	1.27	8.69	3.90	9.62
2002	1.18	0.22	1.38	5.15	4.35	7.25
2003	1.56	0.22	1.66	6.92	4.44	4.23
2004	1.37	0.21	1.37	7.89	5.76	4.85

Table A24. Lower bound estimates for silver hake (southern stock) fishable biomass and upper bound estimates for fishing mortality based on relative efficiency of NEFSC and Supplemental survey bottom trawls and NEFSC fall survey data.

(EDITOR'S NOTE: THIS PART OF THE WORKING GROUP REPORT HAS BEEN OMITTED. IT WAS NOT ACCEPTED BY THE REVIEW PANEL.)

Table A25. Lower bounds for fishable biomass and upper bounds for fishing mortality in the northern silver hake during 1964-2004 based on historical landings and fall survey data.

(EDITOR'S NOTE: THIS PART OF THE WORKING GROUP REPORT HAS BEEN OMITTED. IT WAS NOT ACCEPTED BY THE REVIEW PANEL.)

Table A26. Lower bounds for fishable biomass and upper bounds for fishing mortality in the southern silver hake during 1964-2004 based on historical landings and fall survey data.

(EDITOR'S NOTE: THIS TABLE FROM THE WORKING GROUP REPORT HAS BEEN OMITTED. IT WAS NOT ACCEPTED BY THE REVIEW PANEL.)

Table A27. Total allowable landings (TAL, thousand mt) for silver hake during 2005 based on exploitation index (landings / fall survey biomass index) reference points and average fall survey biomass index during 2002-2004. For comparison, landings averaged 1.71 thousand mt in the north and 6.65 thousand mt in the south during 2002-2004. The CV is for the 2002-2004 mean biomass index and measures uncertainty in the TAL calculation assuming that the reference points are exact.

Stock Area	Exploitation Index		2002-2004 Mean Biomass Index	TAL (1000 mt)	CV
	Reference Points Type	Value			
Northern	Both	2.57	6.72	17.27	0.10
Southern	Target	20.63	1.37	28.26	0.13
Southern	Threshold	34.39		47.11	0.13

SILVER HAKE FIGURES

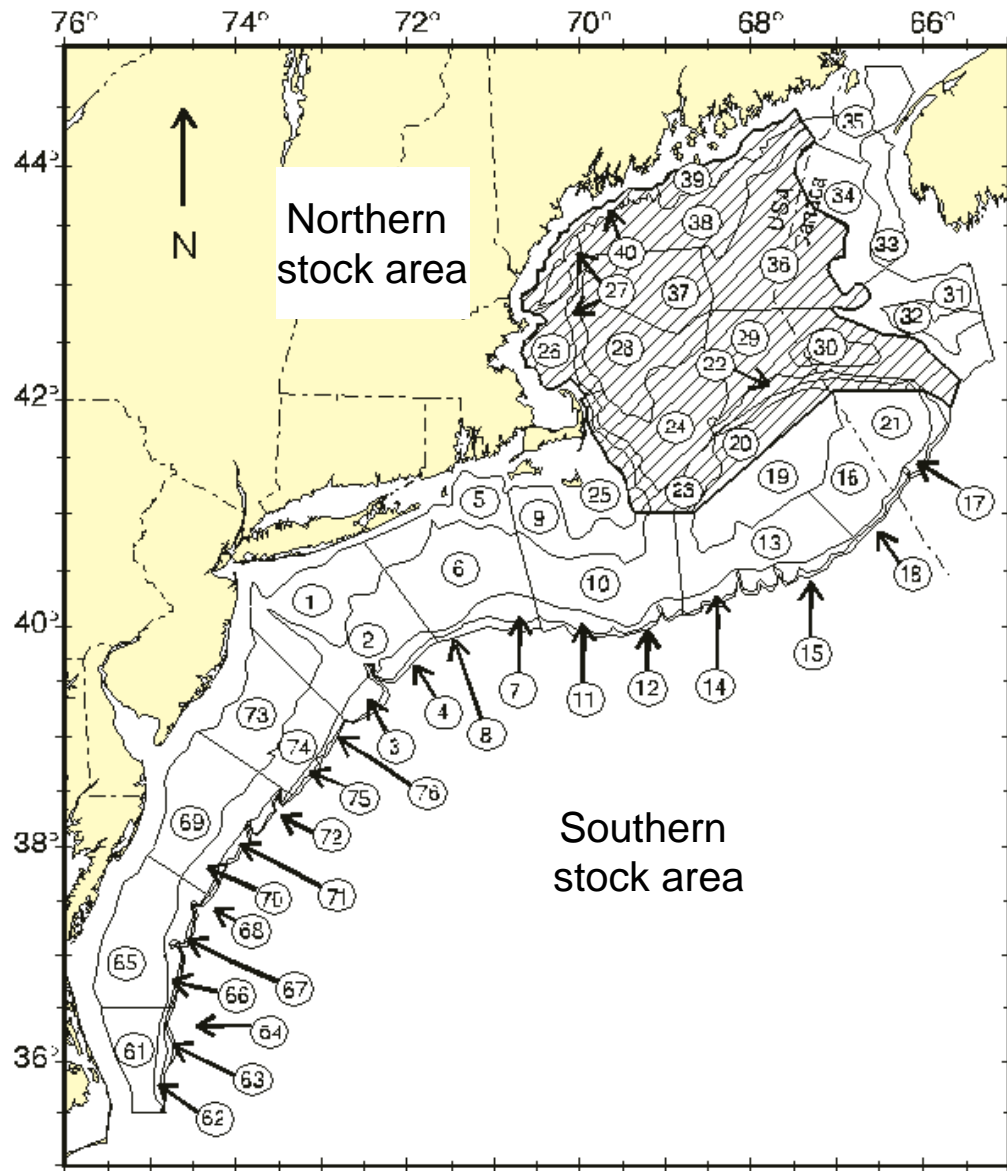


Figure A1. Silver hake stock areas in US waters with NEFSC offshore survey strata. The stratum labeled “73” is, for example, stratum 01730. Numerous inshore survey strata, where silver hake also occur, are not shown. The northern stock area is shown by diagonal lines.

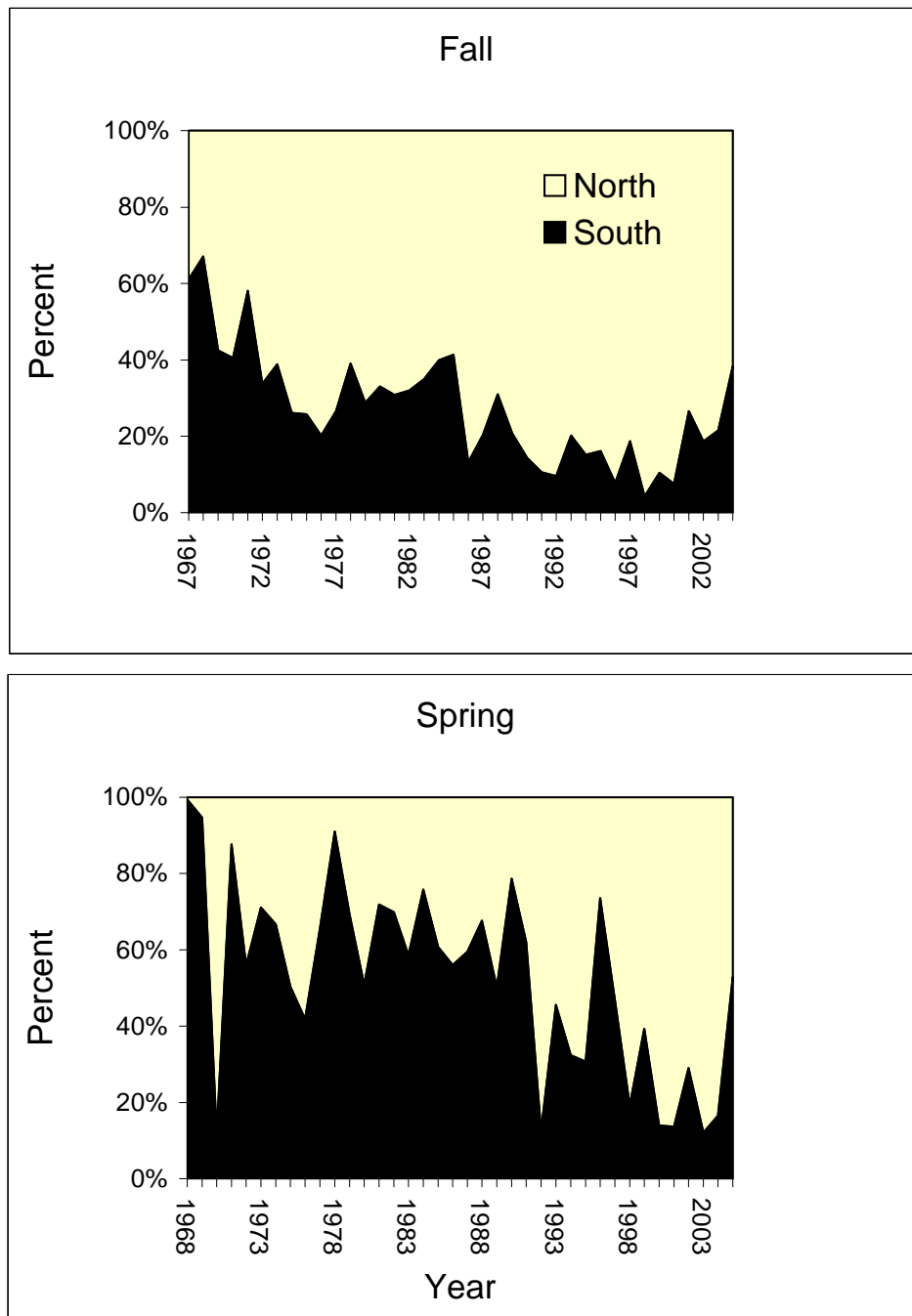


Figure A2. Percent of minimum swept area biomass in the northern and southern stock areas based on NEFSC fall surveys during 1967-2004 and NEFSC spring surveys during 1968-2005. Traditional (consistently occupied offshore strata) were used for survey data.

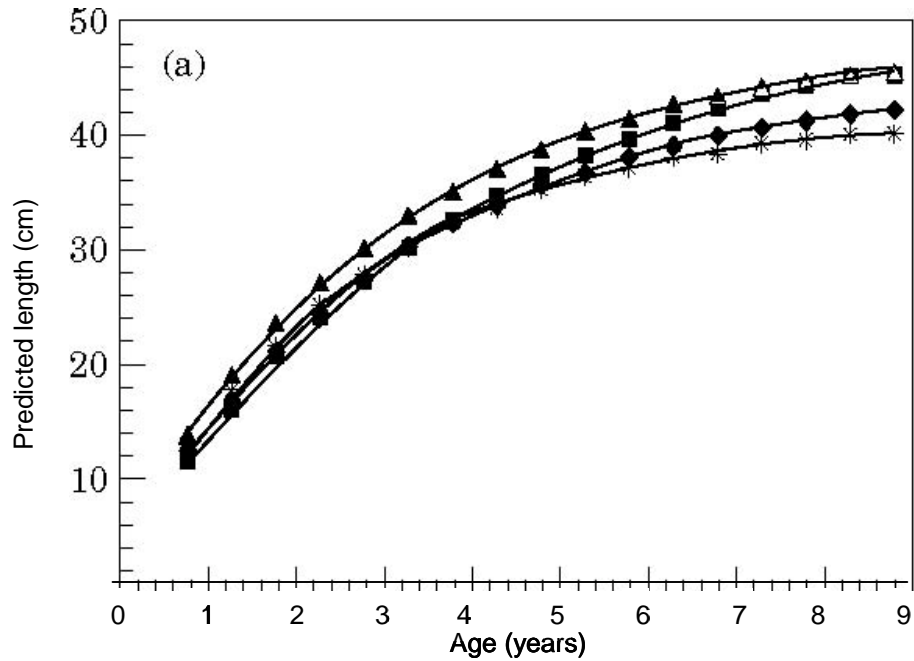


Figure A3. “Typical” growth curves for silver hake from NEFSC fall surveys along the northeast coast between the Gulf of Maine and Mid-Atlantic during 1975-1980 (from Helser 1996).

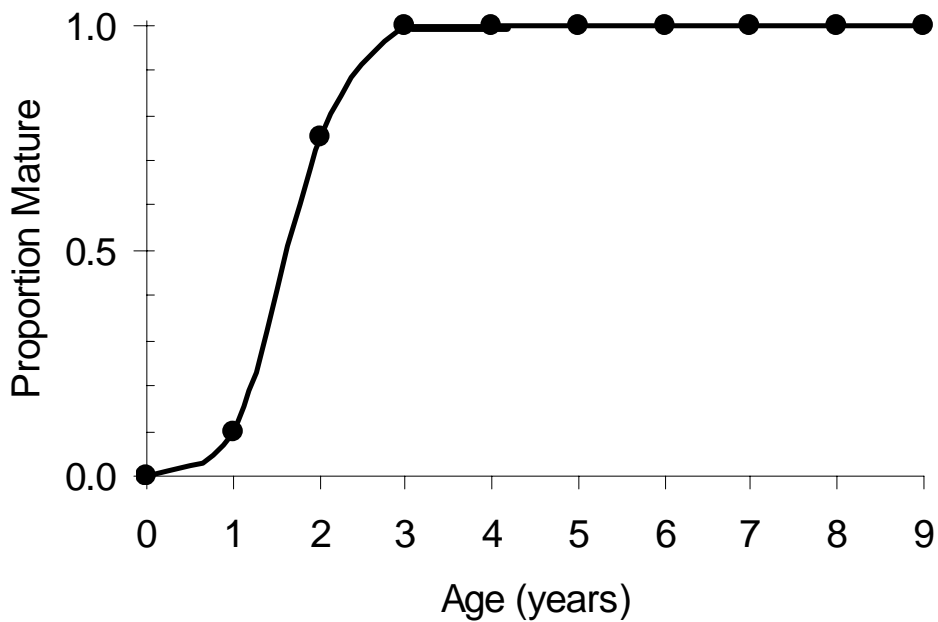


Figure A4. Maturity at age for silver hake from Brodziak et al. (2001).

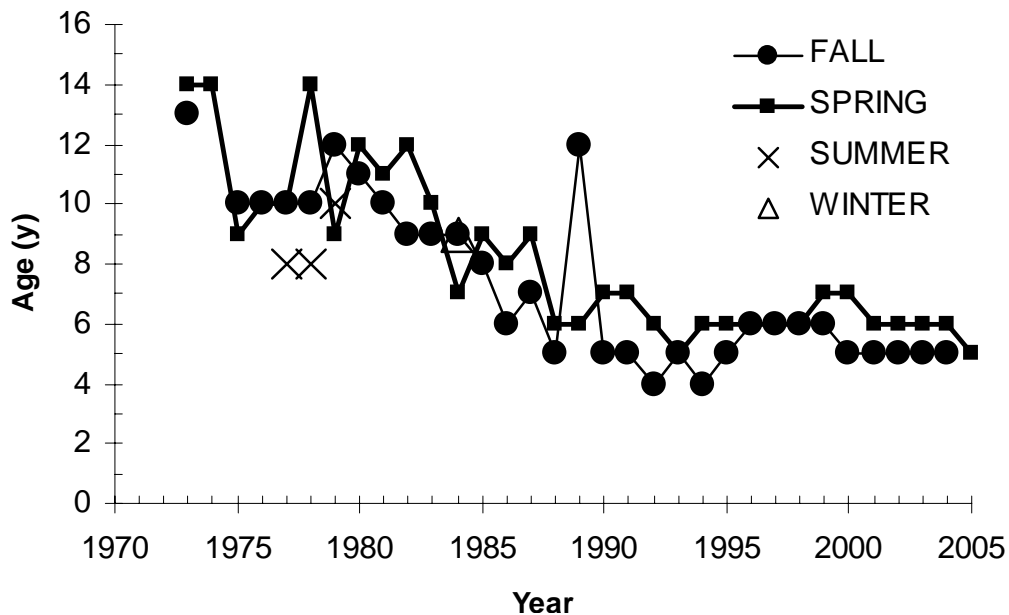


Figure A5. Maximum observed ages by year in NEFSC fall, spring, summer, and winter bottom trawl surveys. Silver hake in summer and winter surveys are not routinely aged. Silver hake age data are currently being audited and are preliminary.

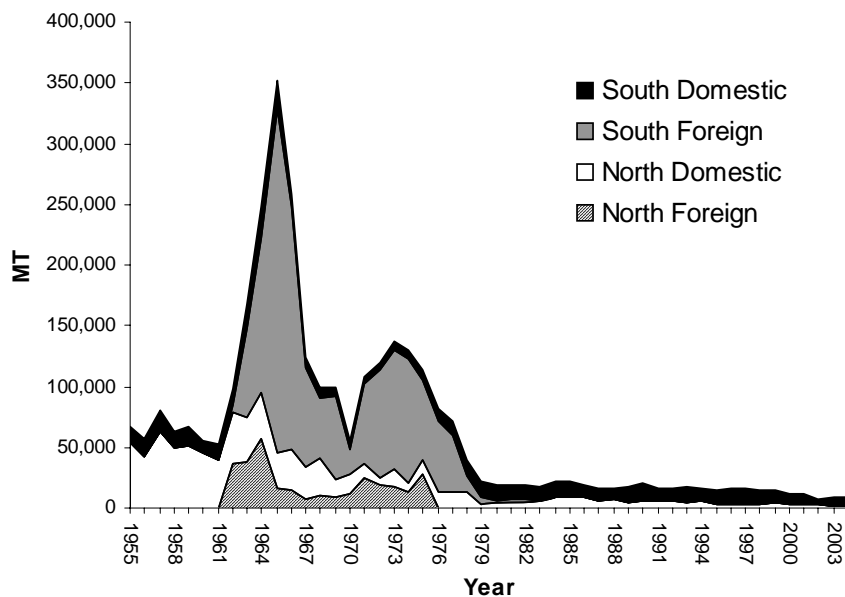


Figure A6. Silver hake landings (mt) by stock area during 1955-2004 for foreign and domestic fishing fleets.

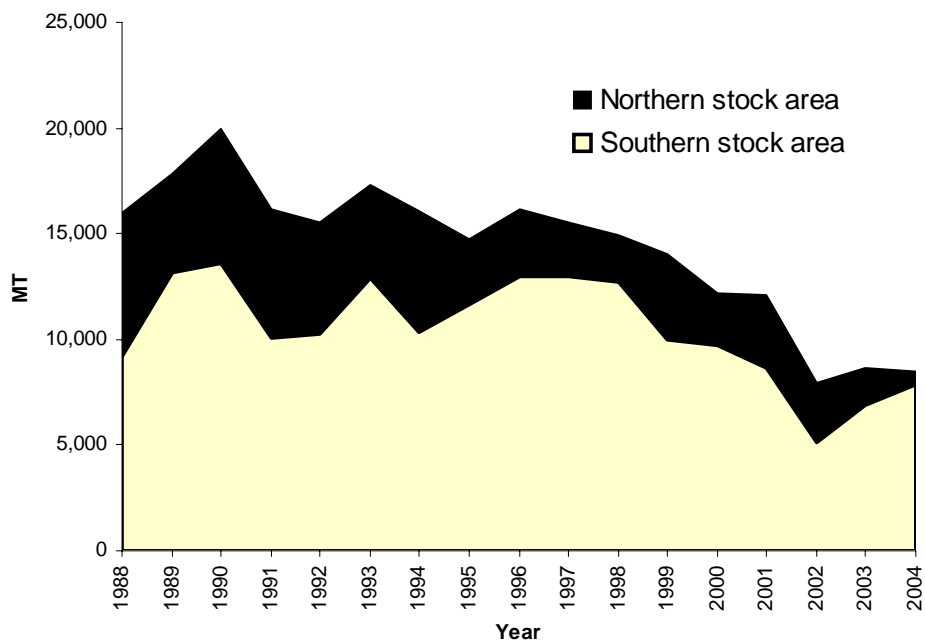


Figure A7. Silver hake landings (mt) in the US domestic fishery by stock area during 1988-2004.

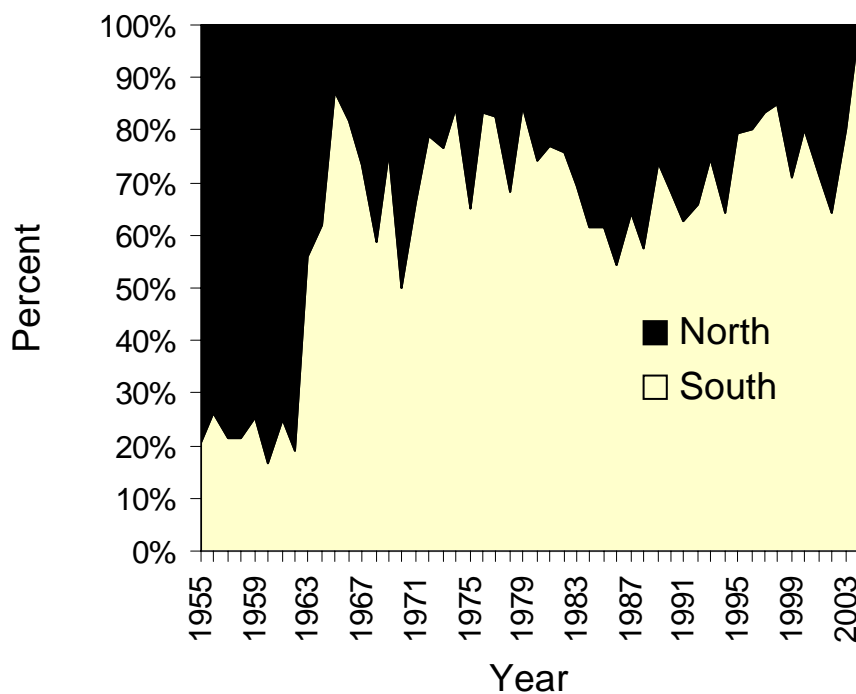


Figure A8. Percent of total silver hake landings (domestic + foreign) from the northern and southern stock areas during 1955-2004.

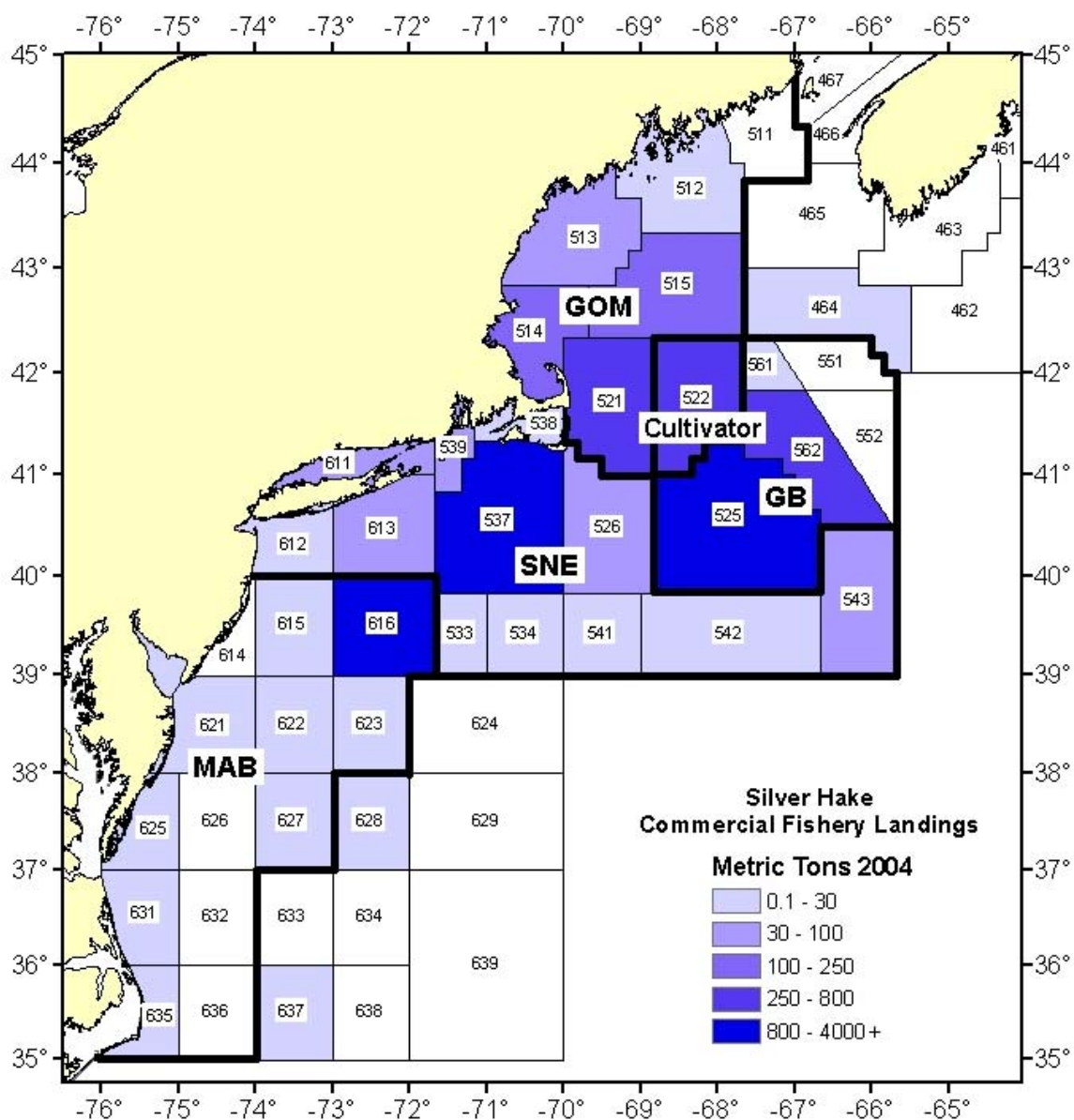


Figure A9. Landings by statistical area (identified by 3-digit numbers) and region during 2004, which was a typical year. Regions are the Gulf of Maine (GOM), Cultivator Shoals, Georges Bank (GB), Southern New England (SNE), and the Mid-Atlantic Bight (MAB).

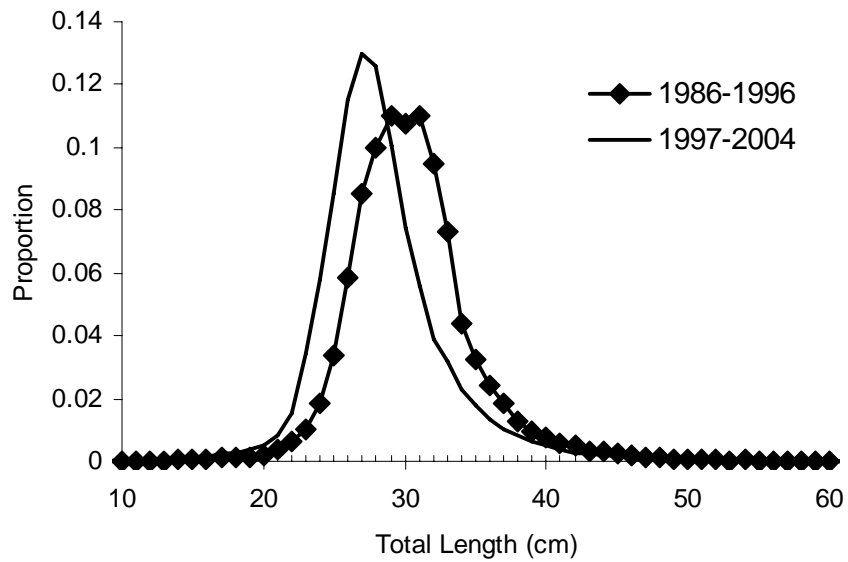


Figure A10. Commercial length composition data for silver hake during 1986-1996 and 1997-2004.

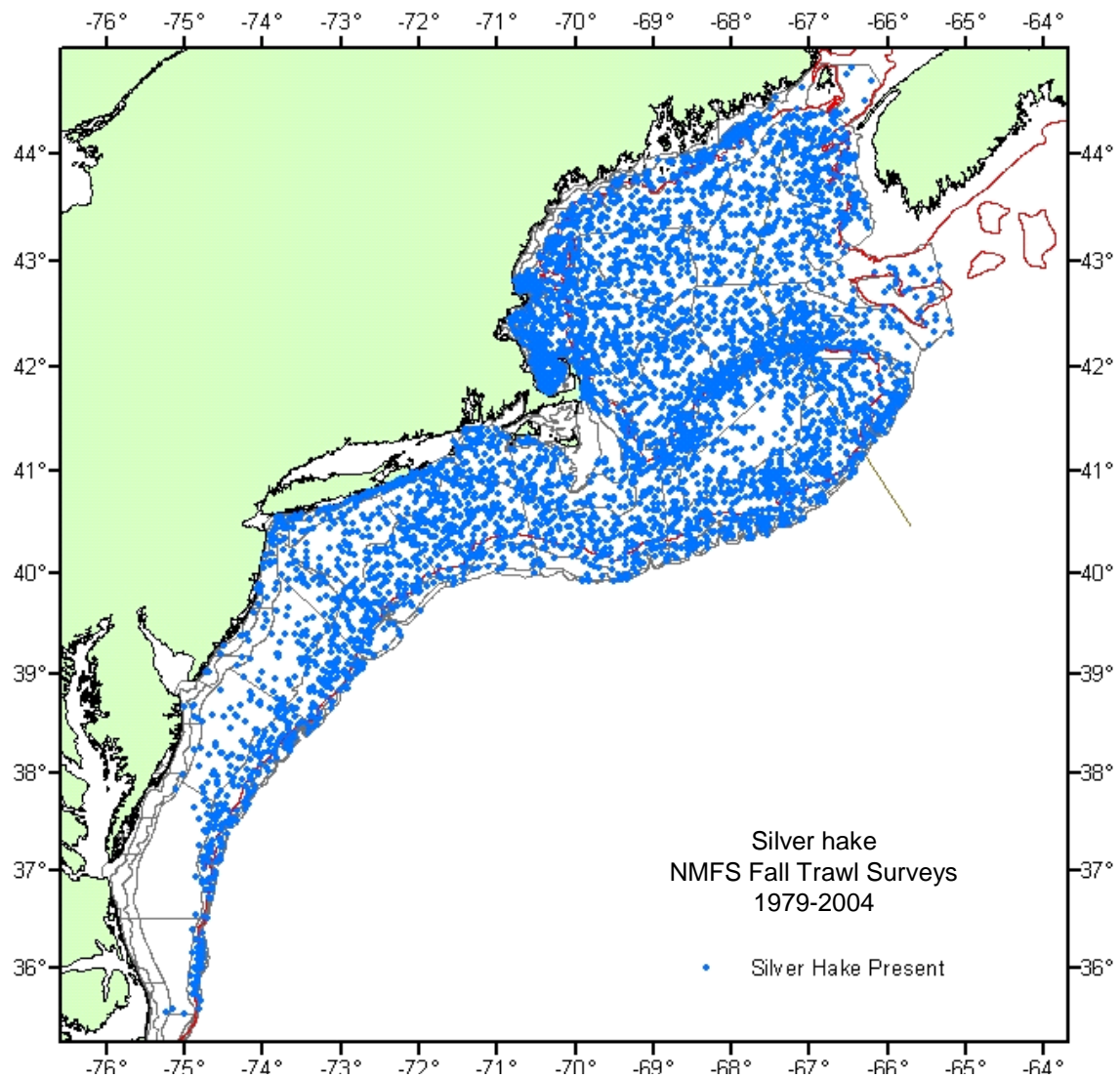


Figure A11. Locations of NEFSC fall bottom trawl survey tows that caught at least one silver hake during 1979-2004, based on all inshore and offshore strata that were sampled.

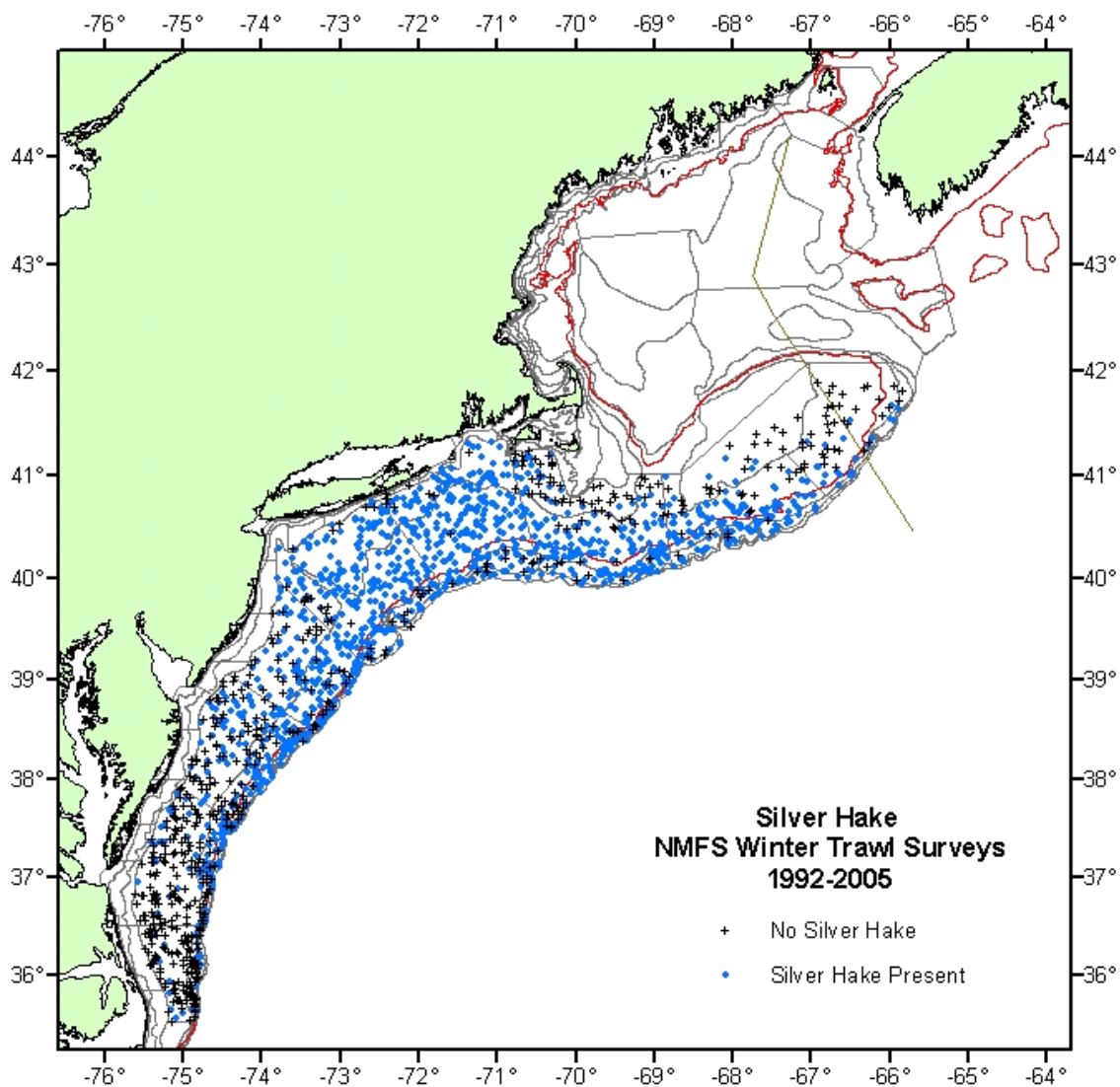


Figure A12. Locations of NEFSC winter bottom trawl survey tows with and without silver hake during 1992-2002, based on all offshore strata that were sampled. The winter survey does not cover strata above southern Georges Bank or inshore strata.

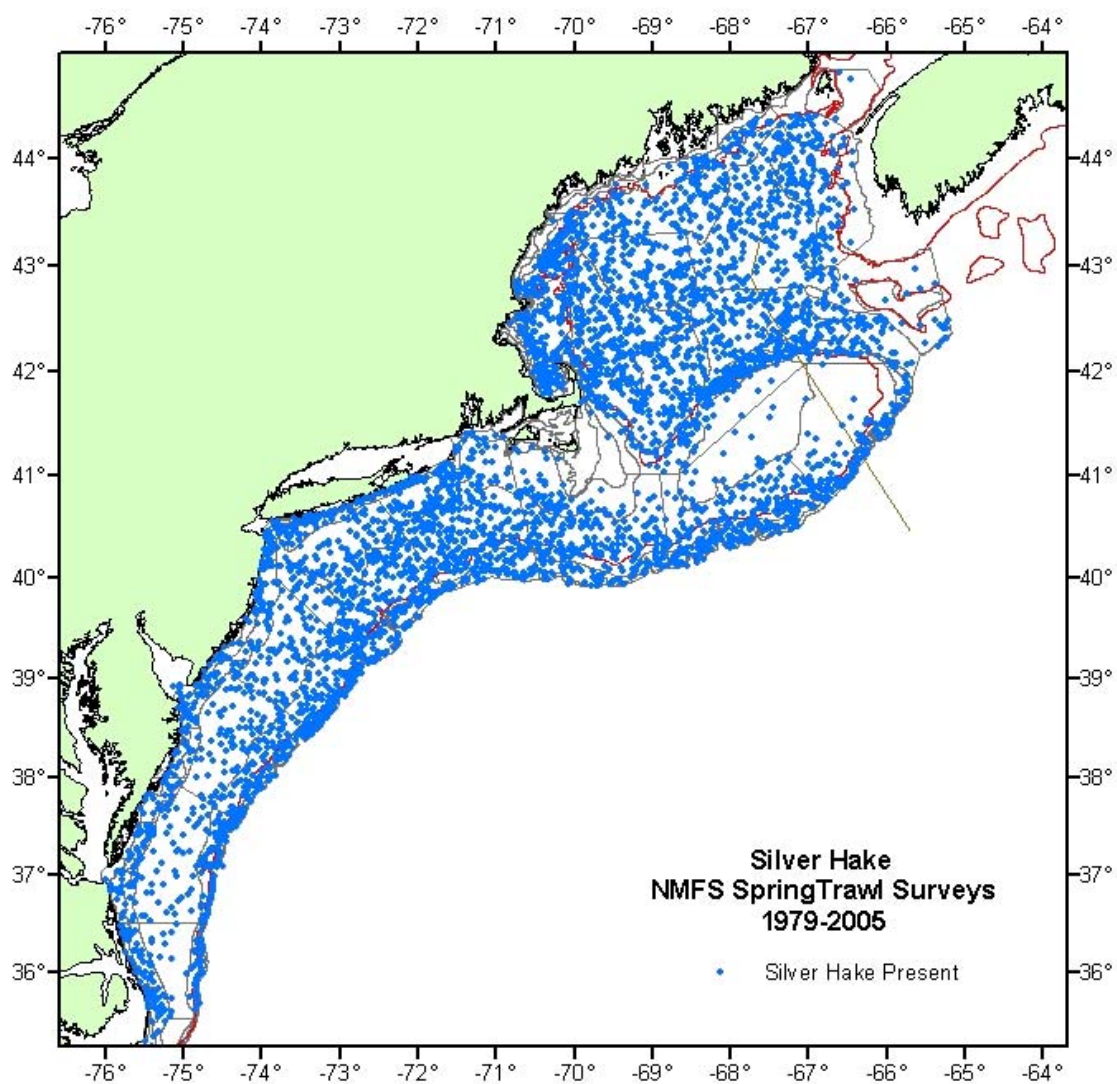


Figure A13. Locations of NEFSC spring bottom trawl survey tows that caught at least one silver hake during 1979-2004, based on all inshore and offshore strata that were sampled.

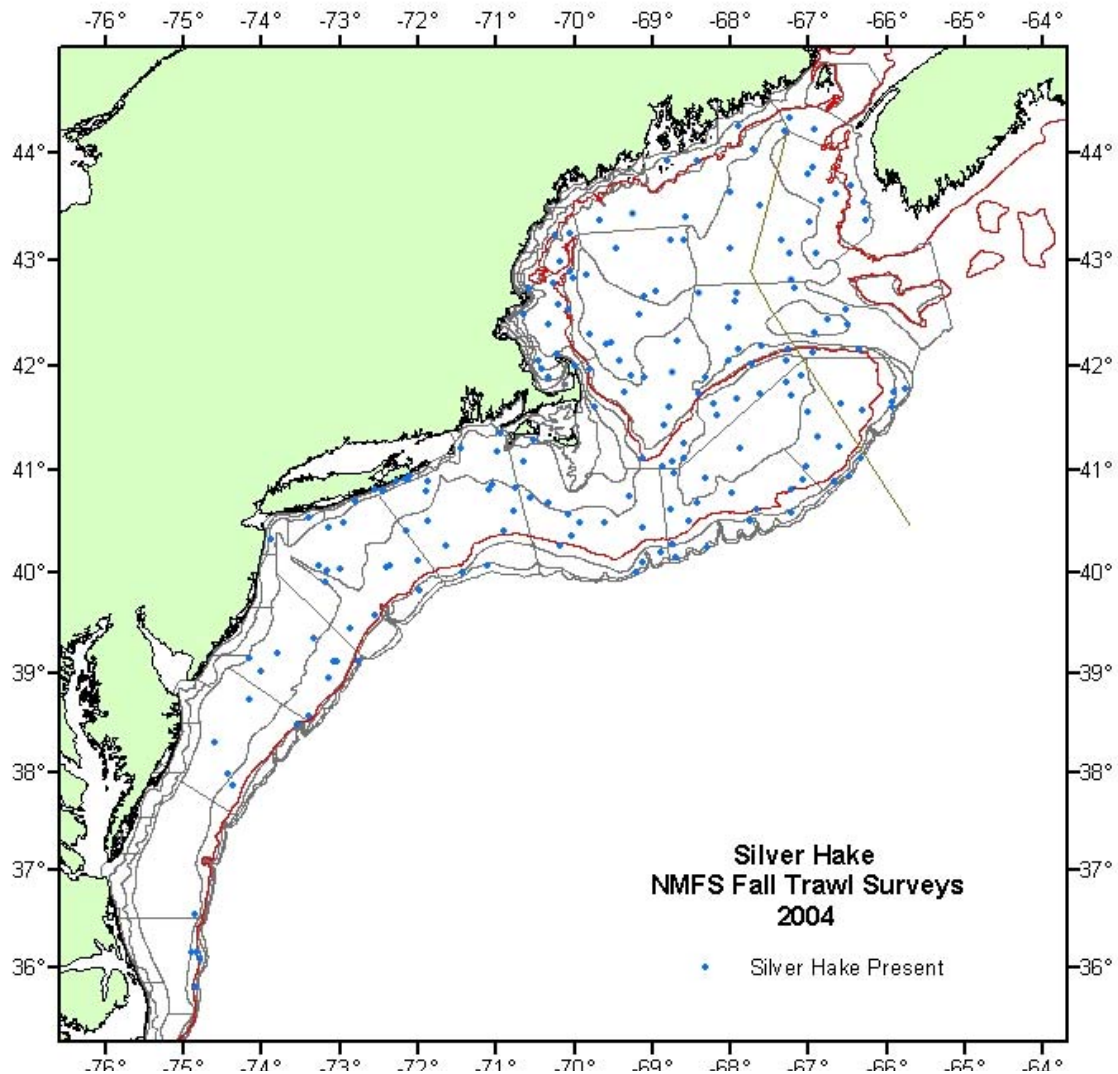


Figure A14. Locations of NEFSC fall bottom trawl survey tows that caught at least one silver hake during 2004, based on all inshore and offshore strata that were sampled.

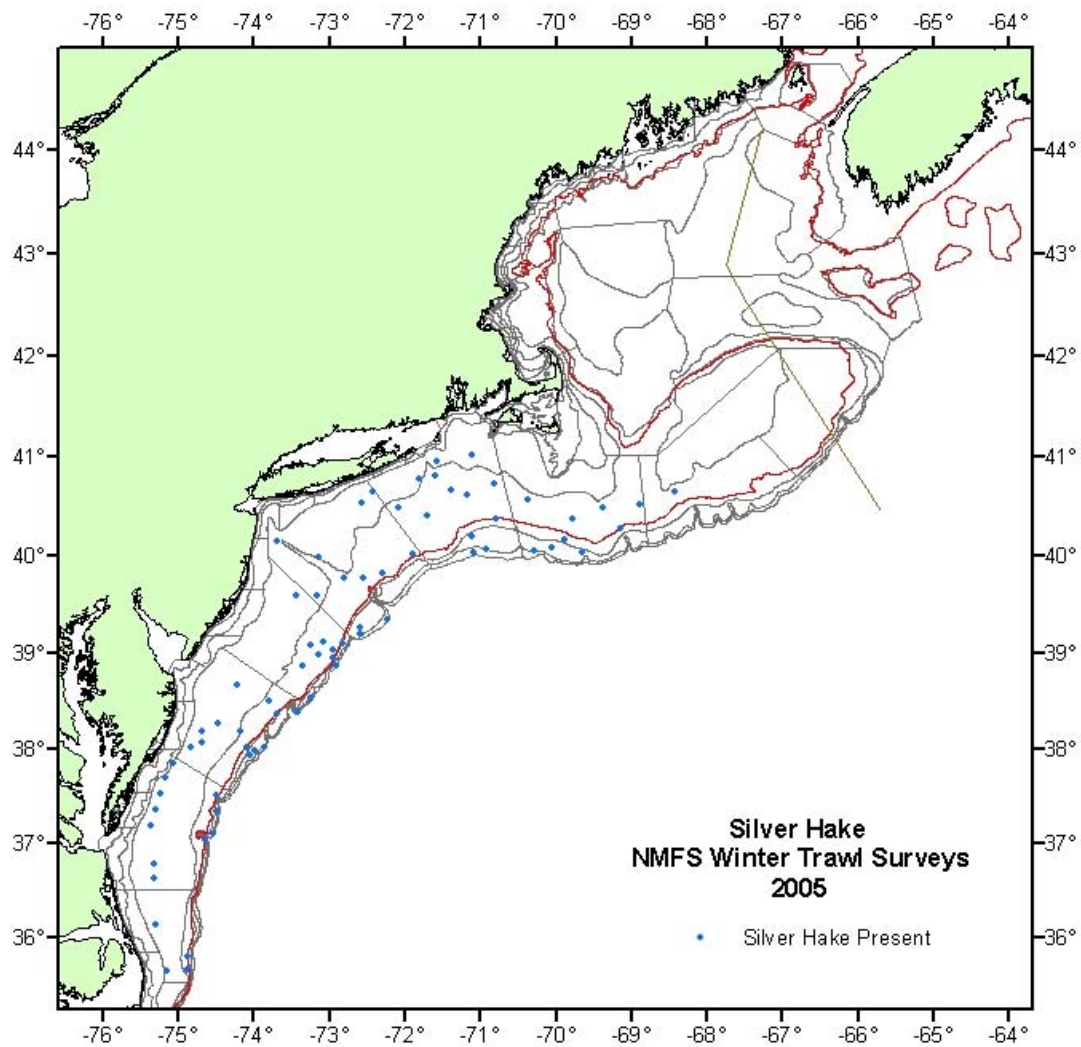


Figure A15. Locations of NEFSC winter bottom trawl survey tows that caught at least one silver hake during 2005, based on all offshore strata that were sampled. The winter survey does not cover strata above southern Georges Bank or inshore strata.

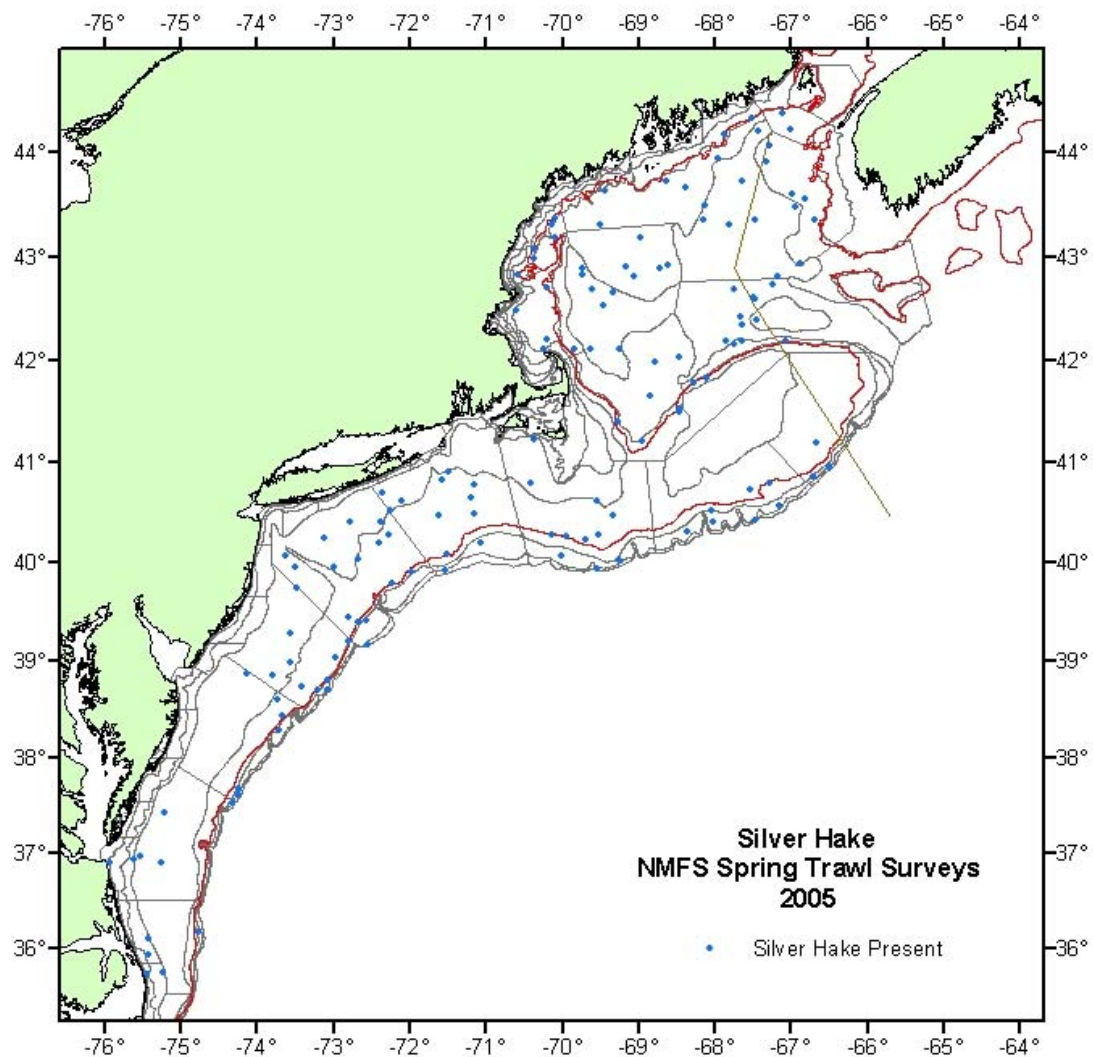


Figure A16. Locations of NEFSC spring bottom trawl survey tows that caught at least one silver hake during 1979-2004, based on all inshore and offshore strata that were sampled.

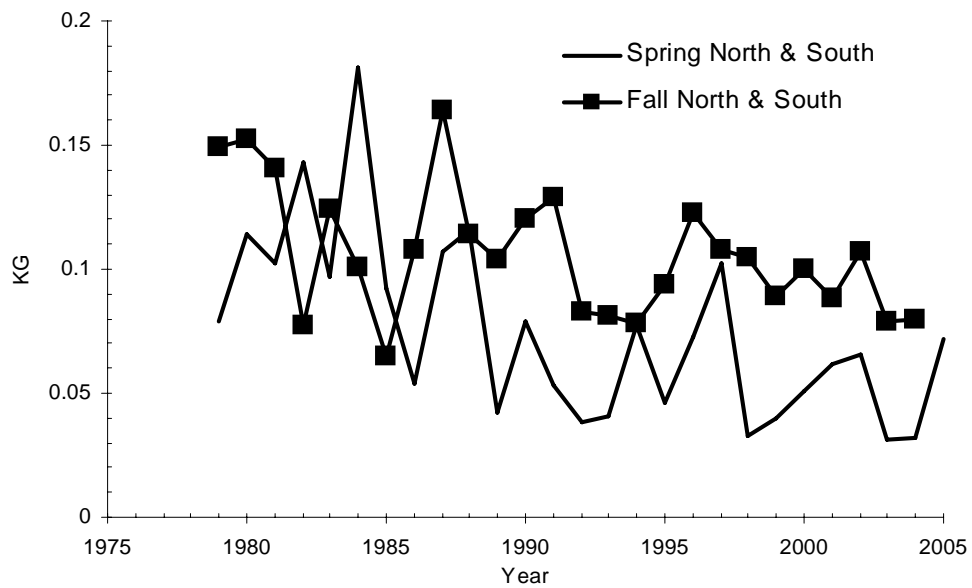


Figure A17. Trends in mean body weight for silver hake in NEFSC surveys during 1979-2005 (special strata set, north and south stock areas combined).

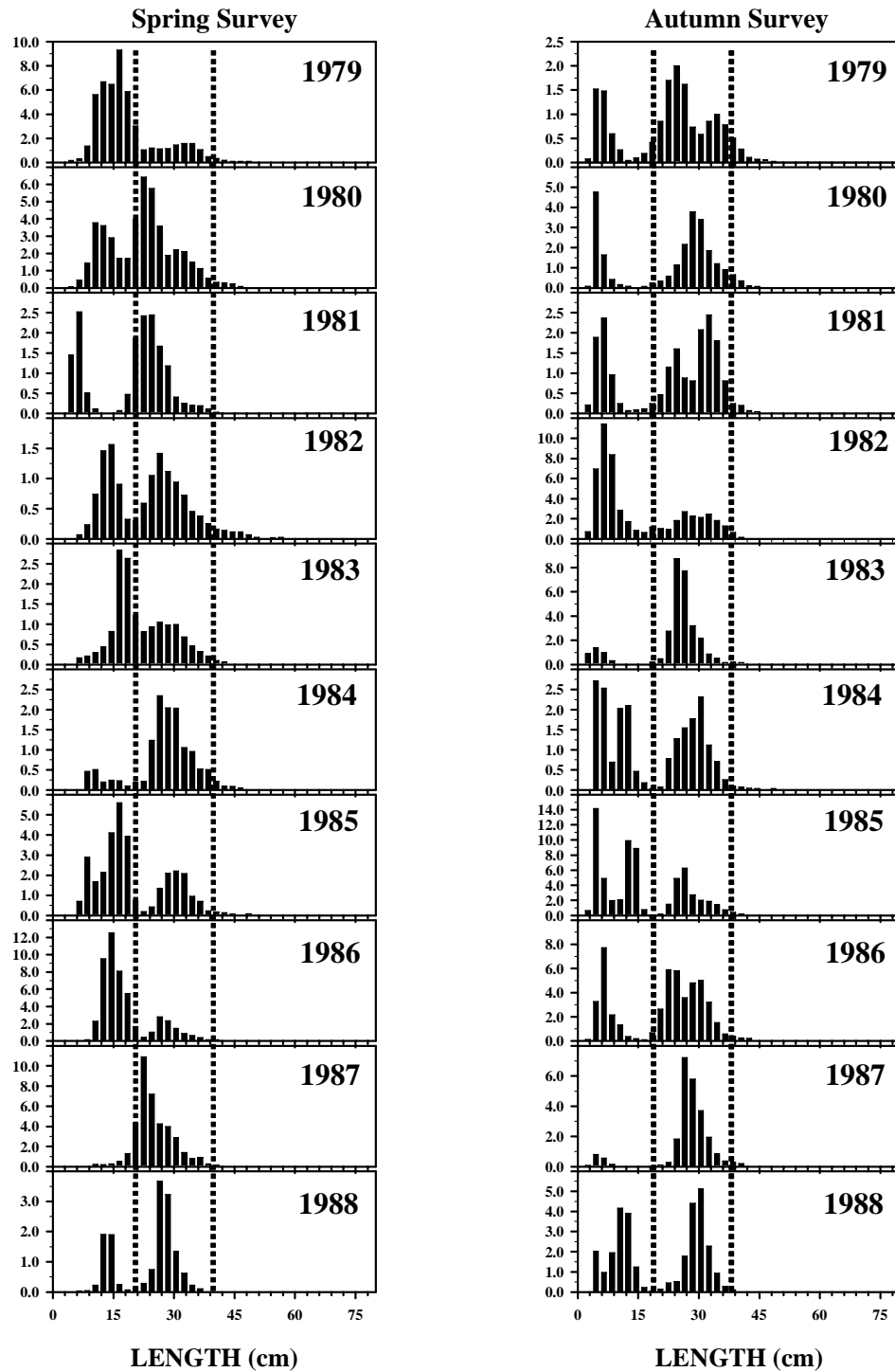


Figure A18. Silver hake length composition from the NEFSC spring and autumn bottom trawl surveys in the combined inshore and offshore regions, 1979-1988 (special strata set). Vertical lines are at approximately 20 cm and 40 cm TL.

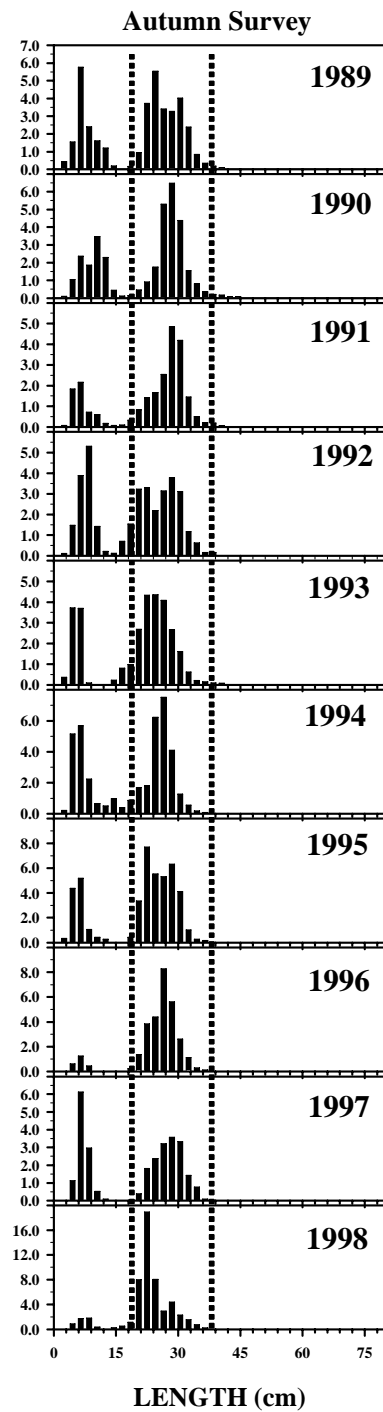
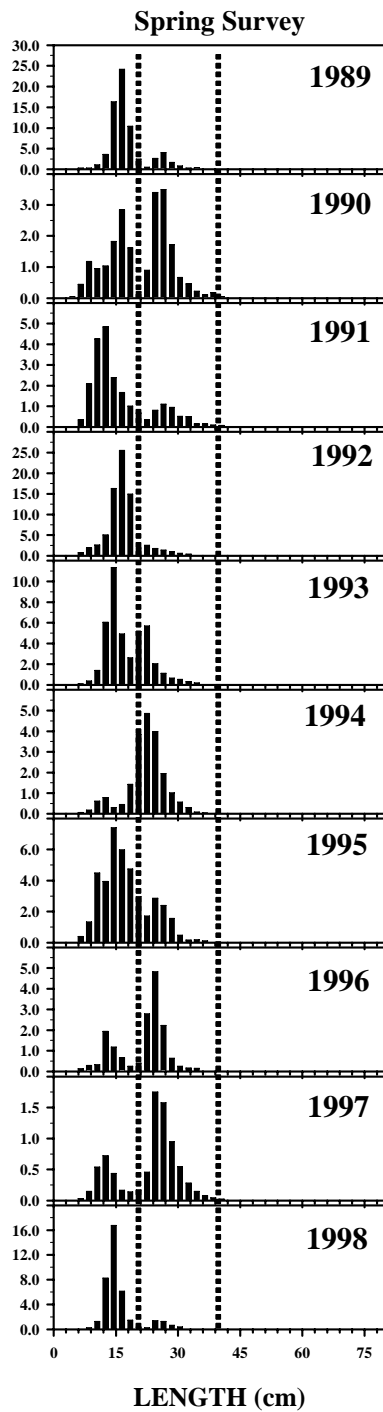


Figure A18. (cont.)

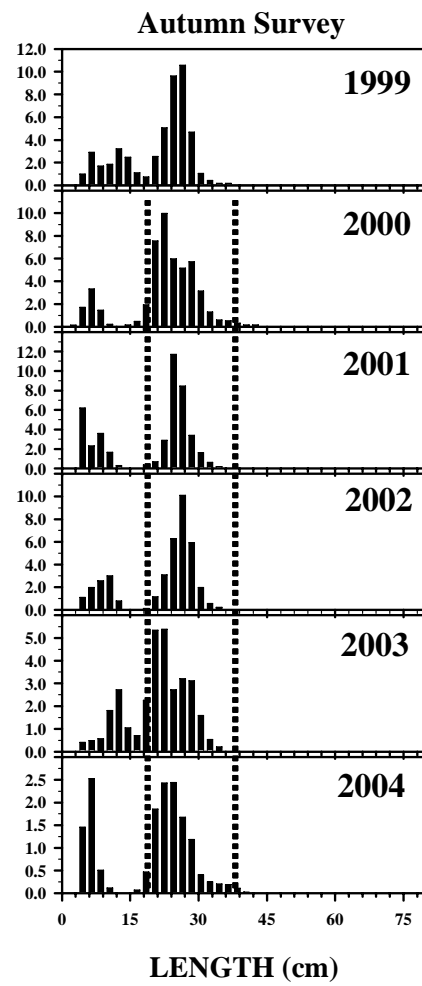
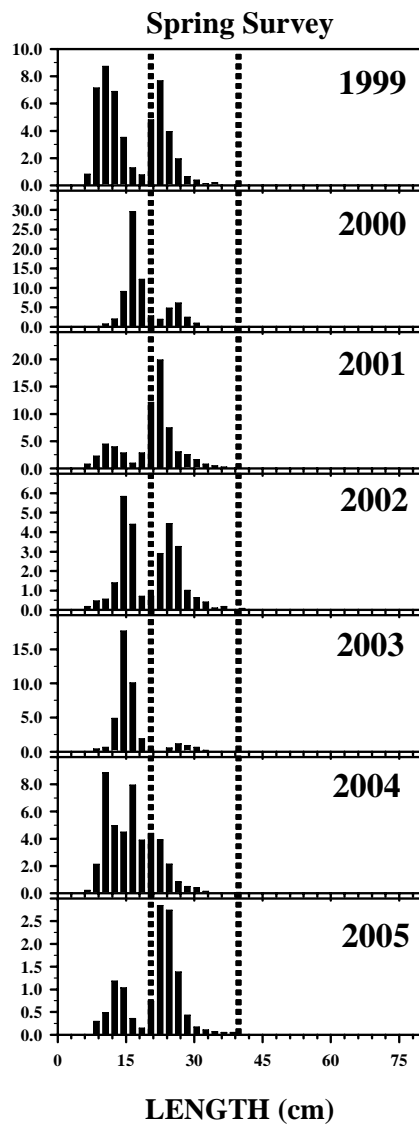


Figure A18. (cont.)

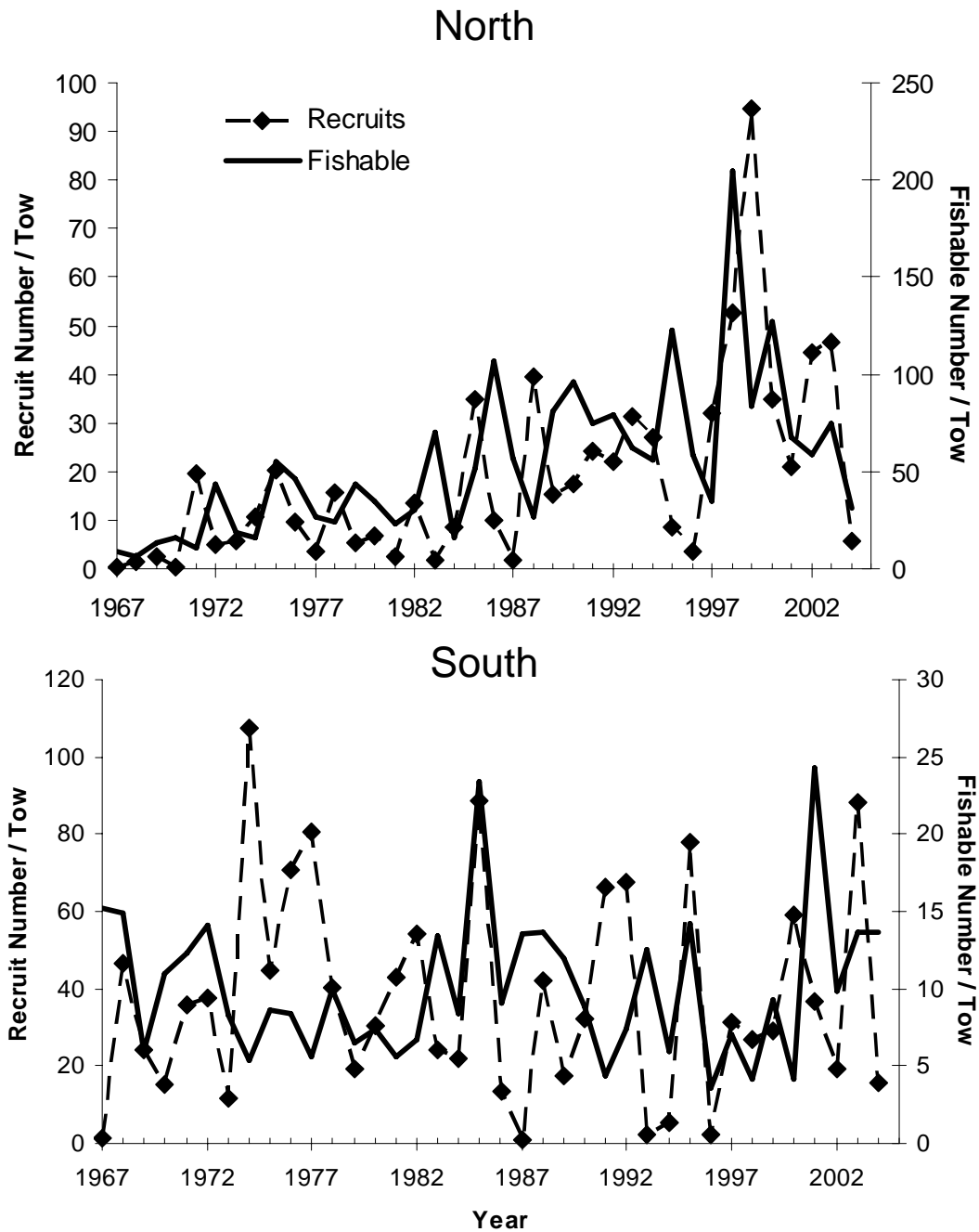


Figure A19. Trends in abundance for recruit (< 20 cm TL) and fishable (= 20 cm TL) silver hake in NEFSC fall surveys.

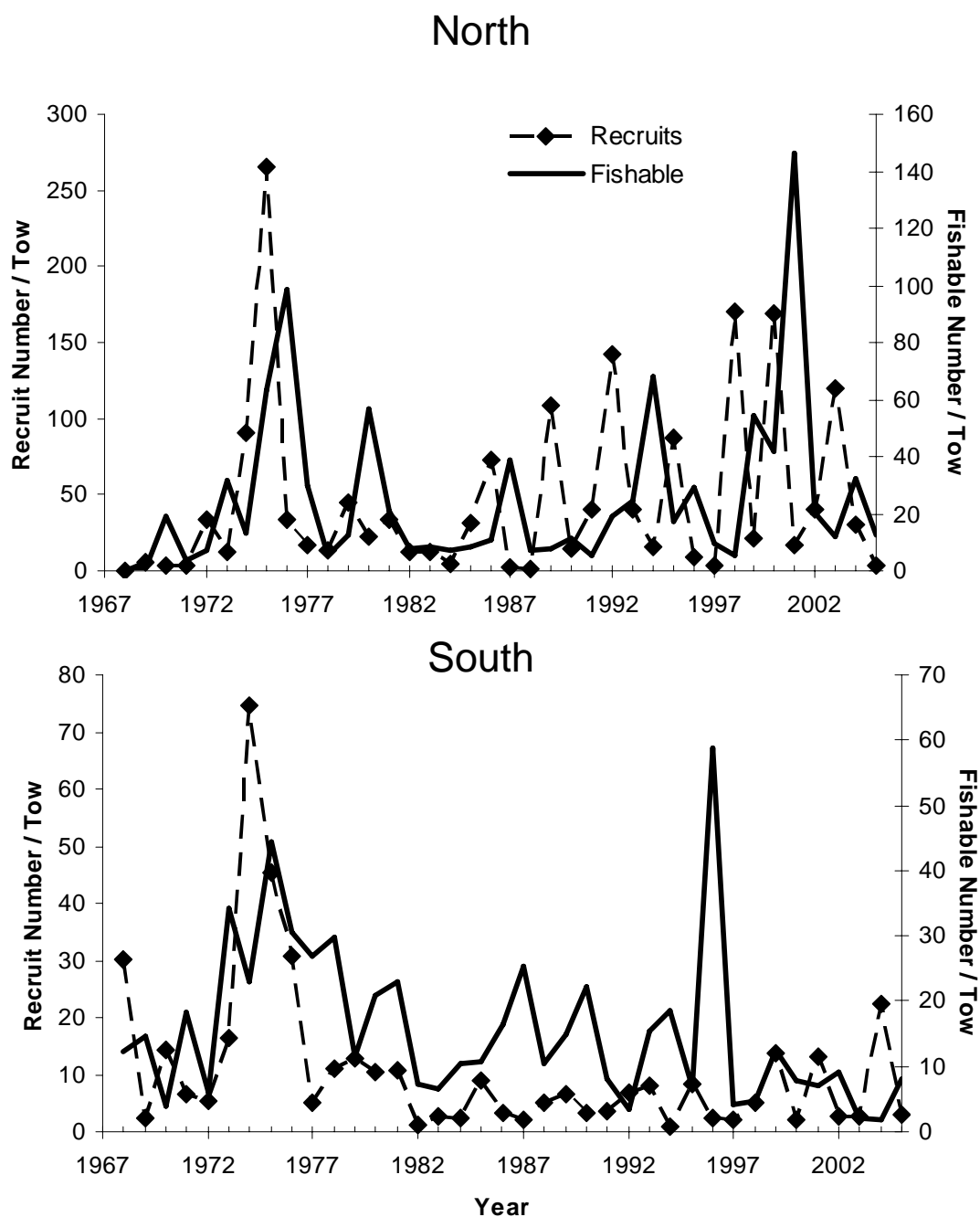


Figure A20. Trends in abundance for recruit (< 20 cm TL) and fishable (= 20 cm TL) silver hake in NEFSC spring surveys.

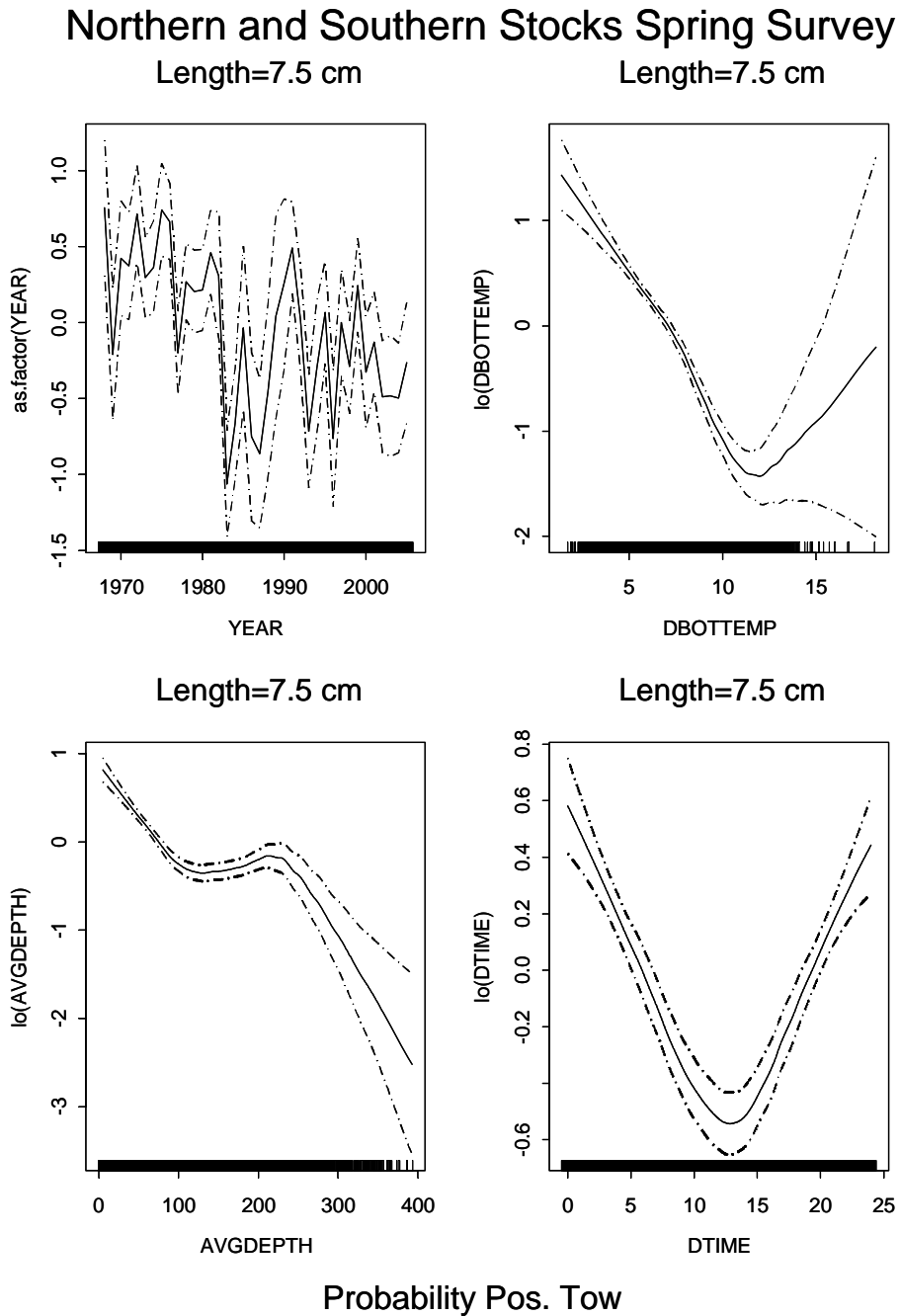
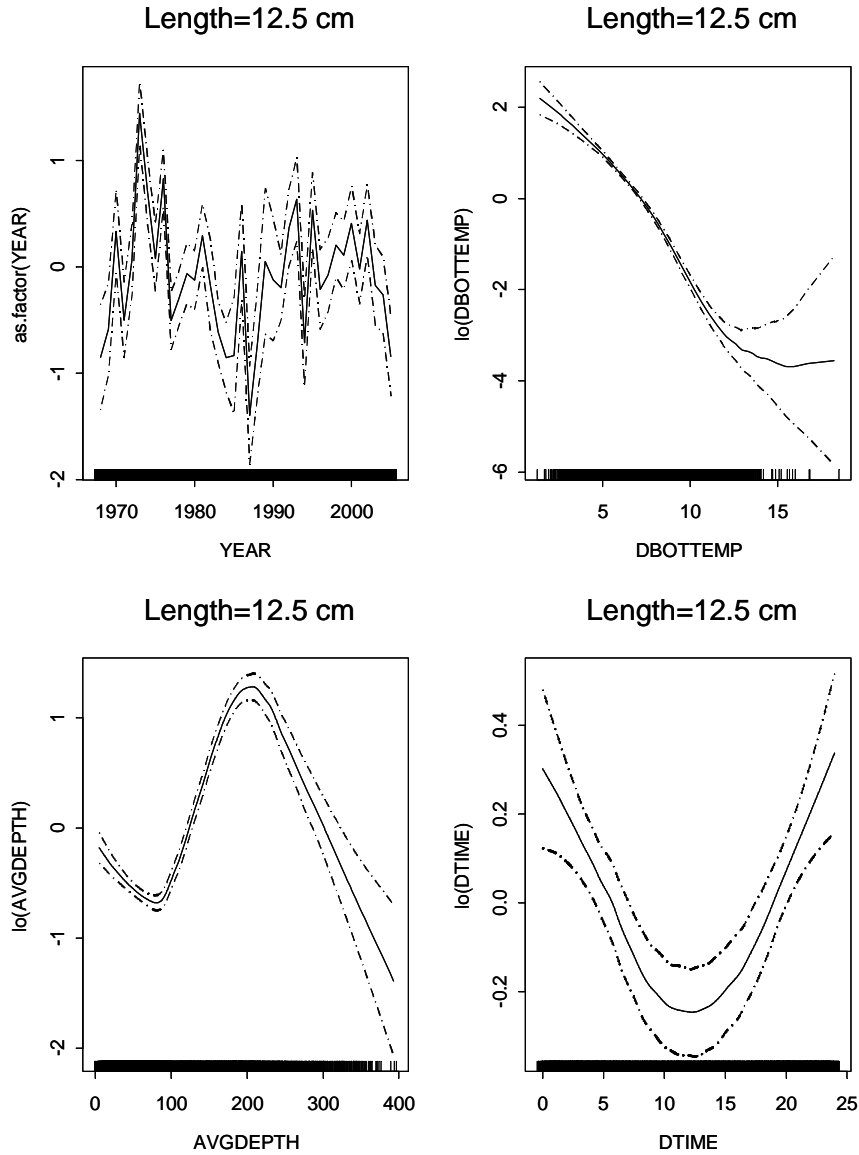


Figure A21. GAM results (partial residual plots for the probability of a positive tow) for silver hake 5-9.9 cm TL in the NEFSC spring survey during 1979-2005 (north and south stock areas combined). The y-axis gives standardized logit-scale residuals. Trends are shown for all terms that were statistically significant based on the AIC criteria.

Northern and Southern Stocks Spring Survey



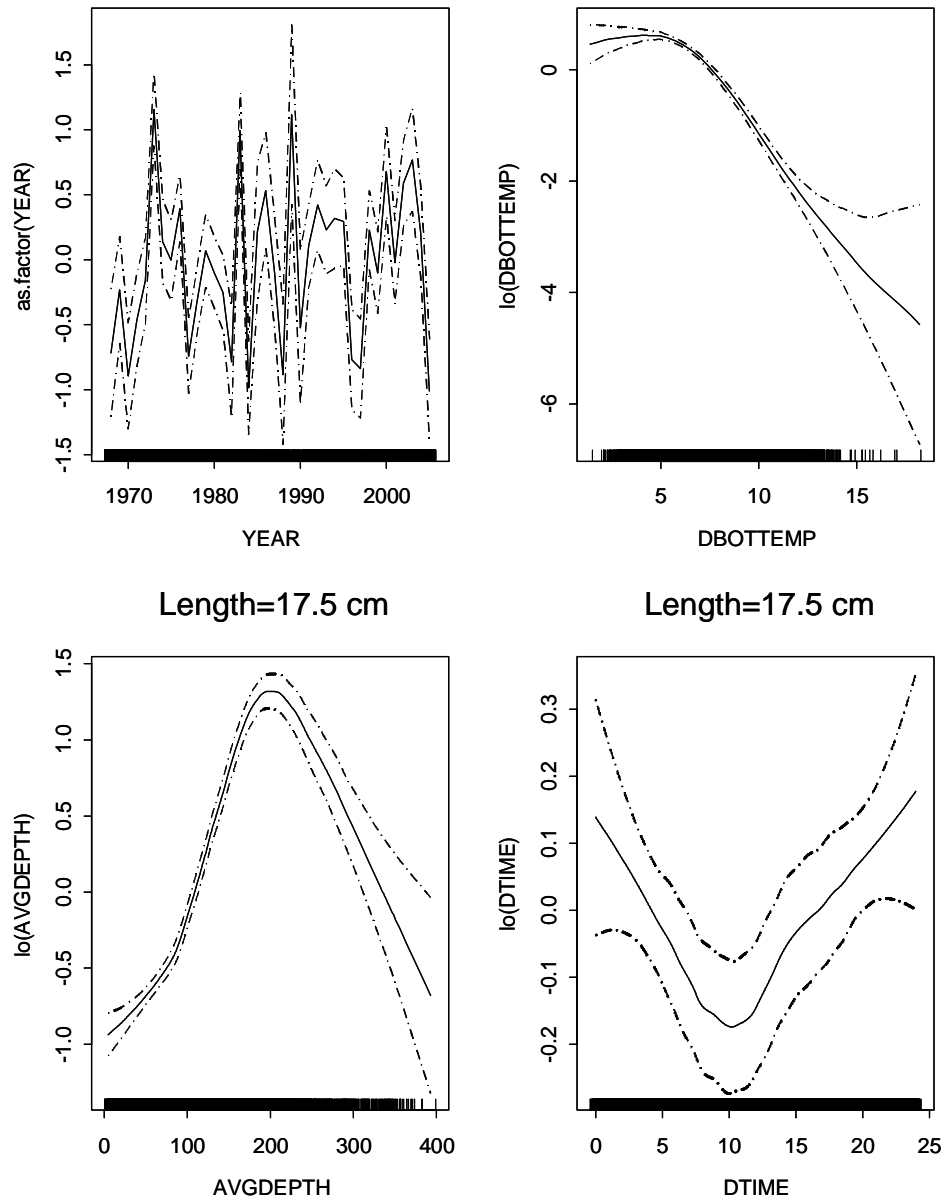
Probability Pos. Tow

Figure A22. GAM results (partial residual plots for the probability of a positive tow) for silver hake 10-14.9 cm TL in the NEFSC spring survey during 1979-2005 (north and south stock areas combined). The y-axis gives standardized logit-scale residuals. Trends are shown for all terms that were statistically significant based on the AIC criteria.

Northern and Southern Stocks Spring Survey

Length=17.5 cm

Length=17.5 cm



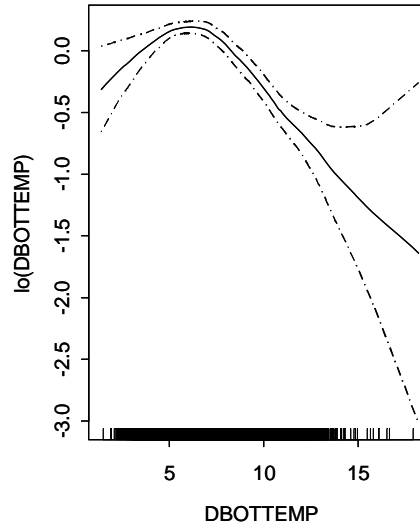
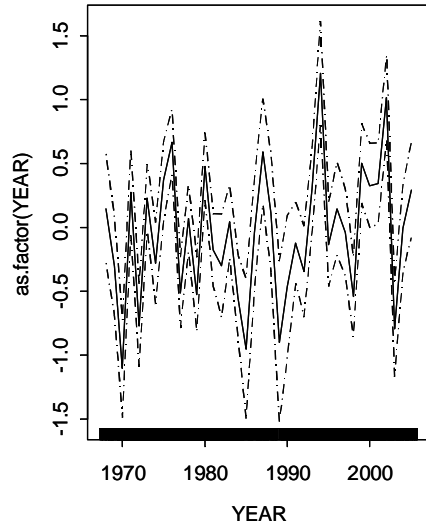
Probability Pos. Tow

Figure A23. GAM results (partial residual plots for the probability of a positive tow) for silver hake 15-19.9 cm TL in the NEFSC spring survey during 1979-2005 (north and south stock areas combined). The y-axis gives standardized logit-scale residuals. Trends are shown for all terms that were statistically significant based on the AIC criteria.

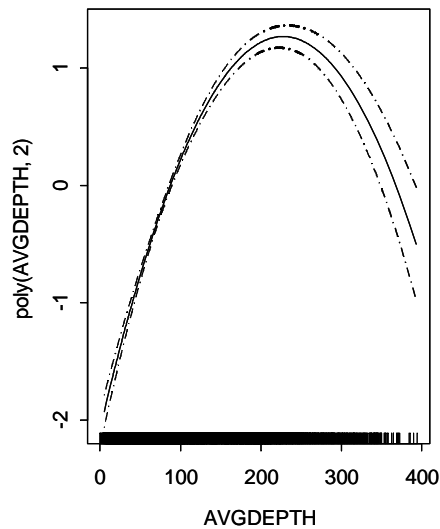
Northern and Southern Stocks Spring Survey

Length=22.5 cm

Length=22.5 cm



Length=22.5 cm



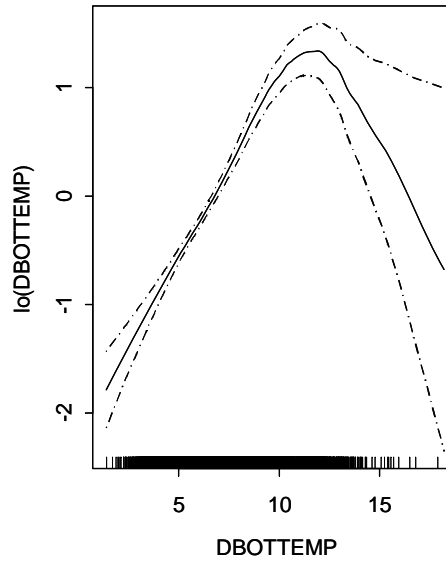
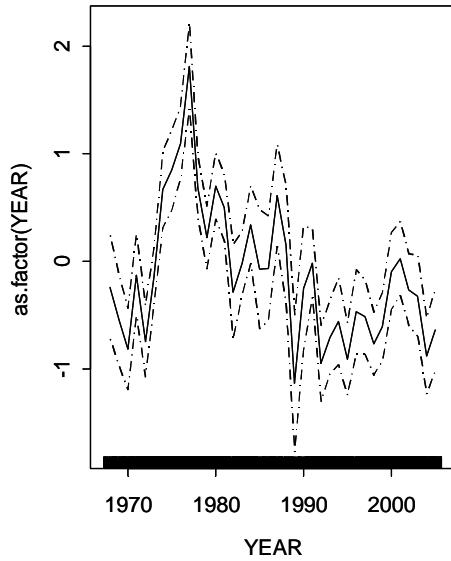
Probability Pos. Tow

Figure A24. GAM results (partial residual plots for the probability of a positive tow) for silver hake 20-24.9 cm TL in the NEFSC spring survey during 1979-2005 (north and south stock areas combined). The y-axis gives standardized logit-scale residuals. Trends are shown for all terms that were statistically significant based on the AIC criteria.

Northern and Southern Stocks Spring Survey

Length=27.5 cm

Length=27.5 cm



Length=27.5 cm

Length=27.5 cm

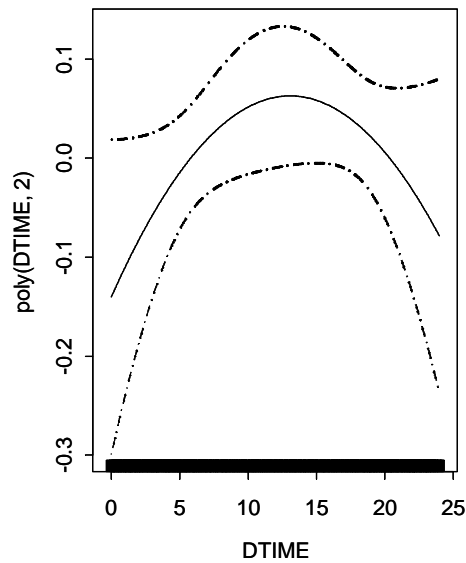
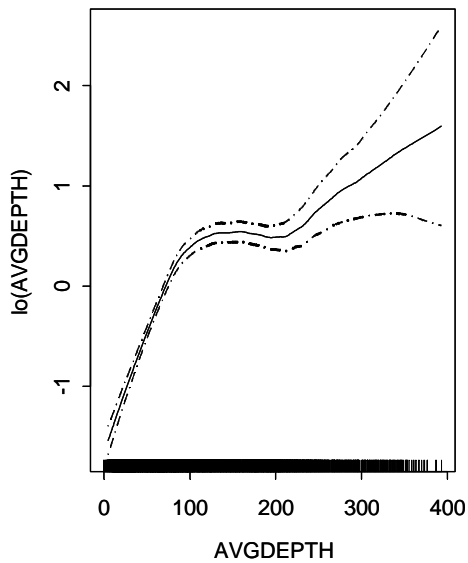


Figure A25. GAM results (partial residual plots for the probability of a positive tow) for silver hake 25+ cm TL in the NEFSC spring survey during 1979-2005 (north and south stock areas combined). The y-axis gives standardized logit-scale residuals. Trends are shown for all terms that were statistically significant based on the AIC criteria.

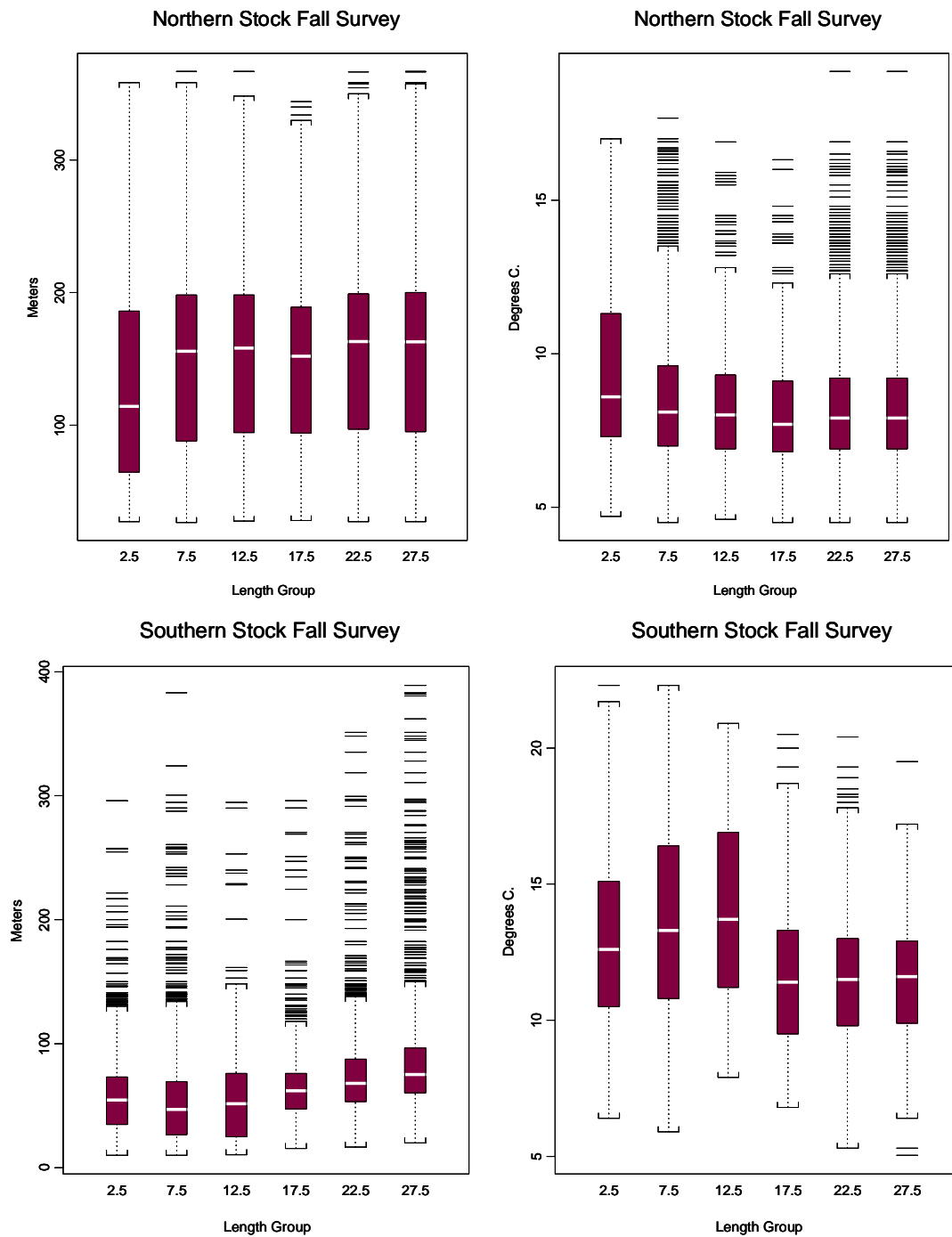


Figure A26. Distributions of depths and bottom temperatures by size and stock for tows that took silver hake in NEFSC fall bottom trawl surveys.

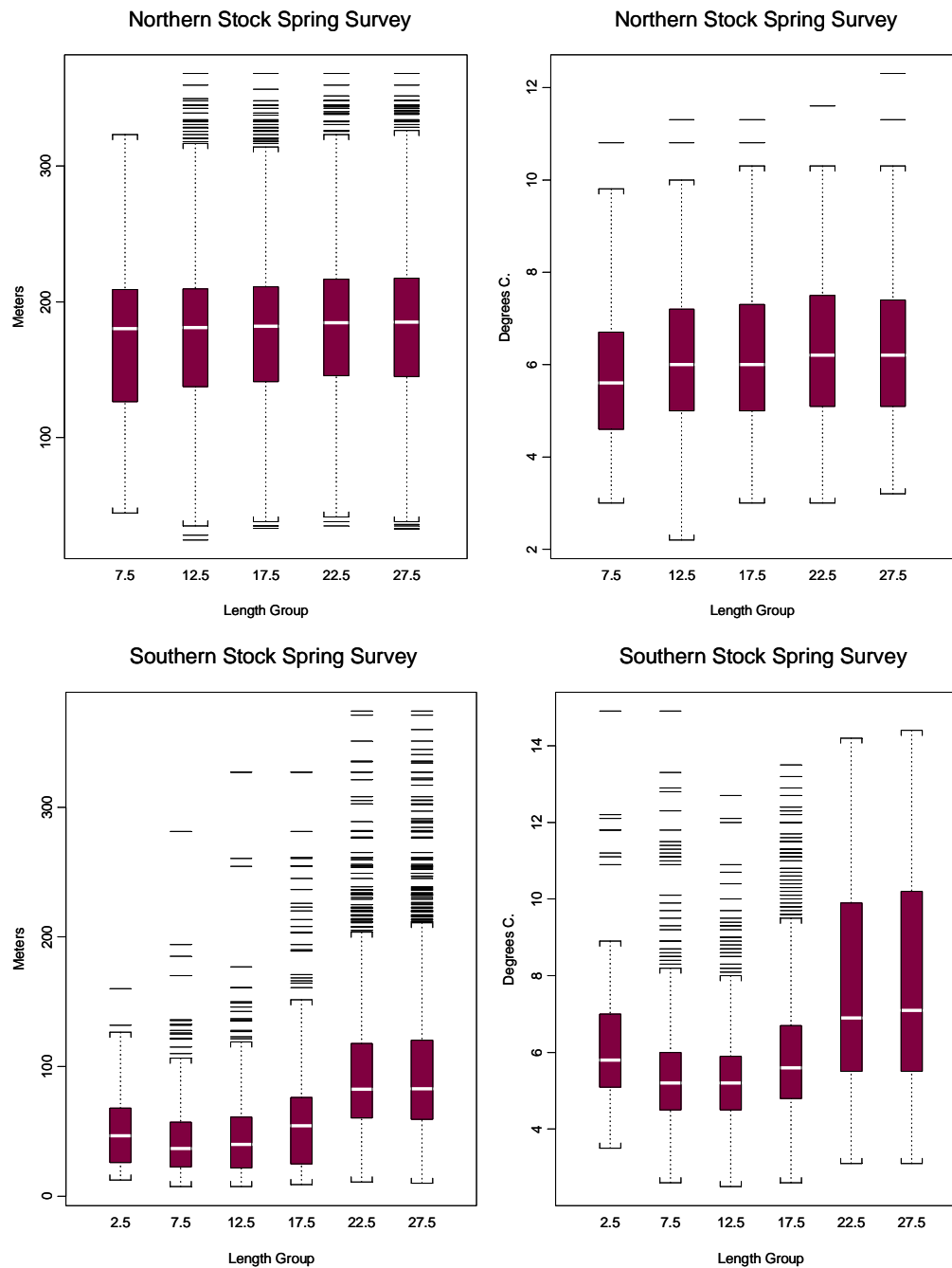


Figure A27. Distributions of depths and bottom temperatures by size and stock for tows that took silver hake in NEFSC spring bottom trawl surveys.

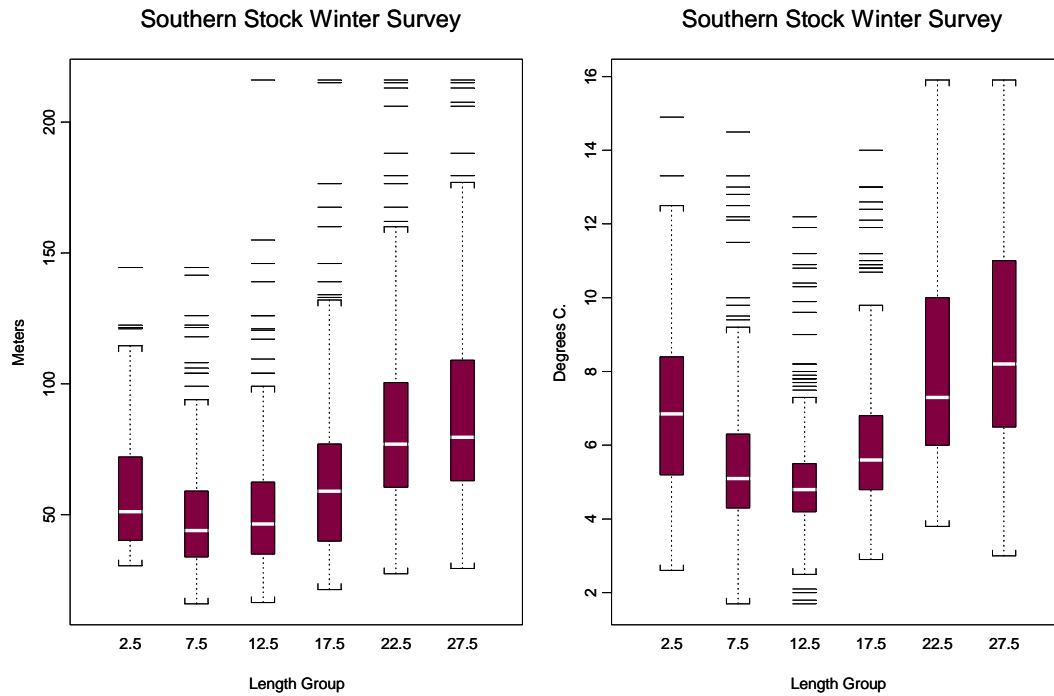


Figure A28. Distributions of depths and bottom temperatures by size and stock for tows that took silver hake in NEFSC winter bottom trawl surveys.

Figure A29. Average position (latitude in left panel and longitude in right) for silver hake in fall bottom trawl surveys in the northern stock area, by size group. Averages are for tows, weighted by catch of the appropriate size group.

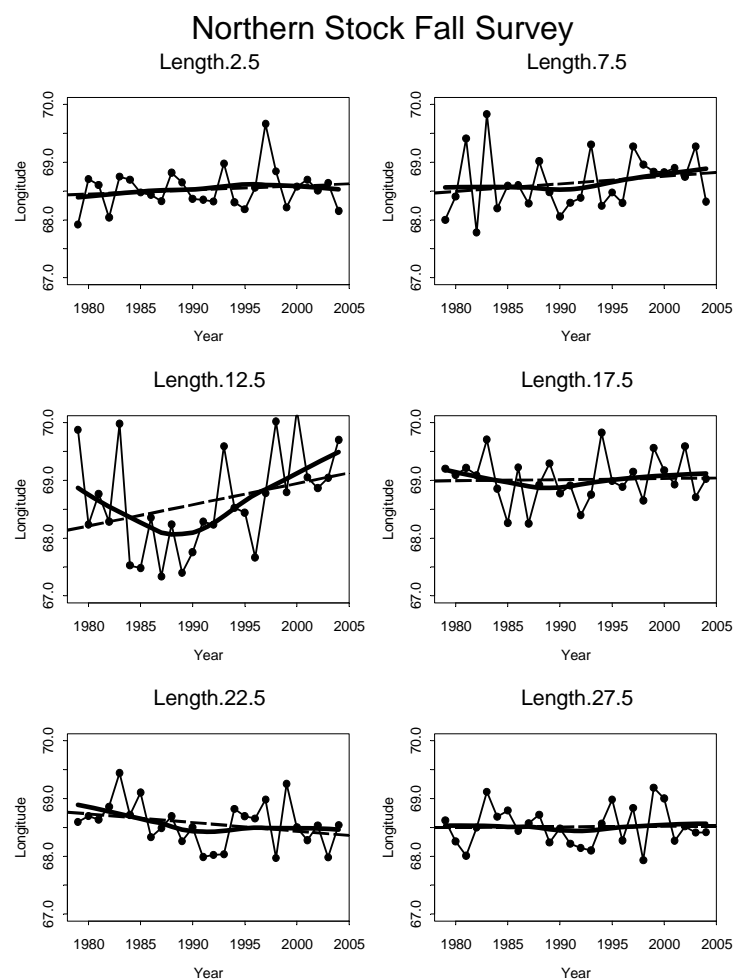
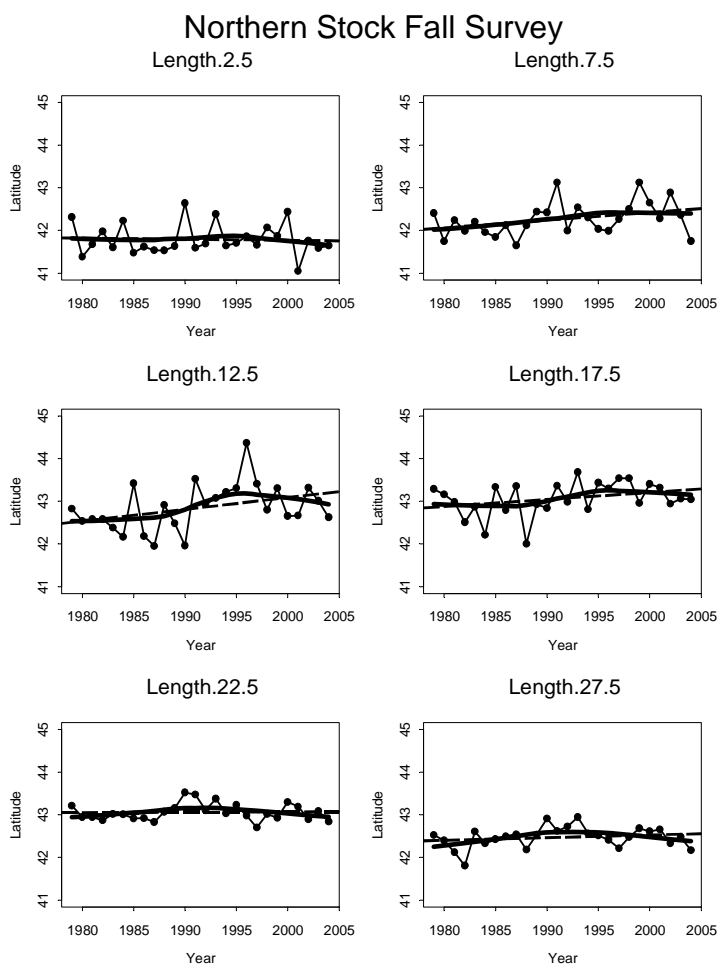


Figure A30. Average position (latitude in left panel and longitude in right) for silver hake in fall bottom trawl surveys in the southern stock area, by size group. Averages are for tows, weighted by catch of the appropriate size group.

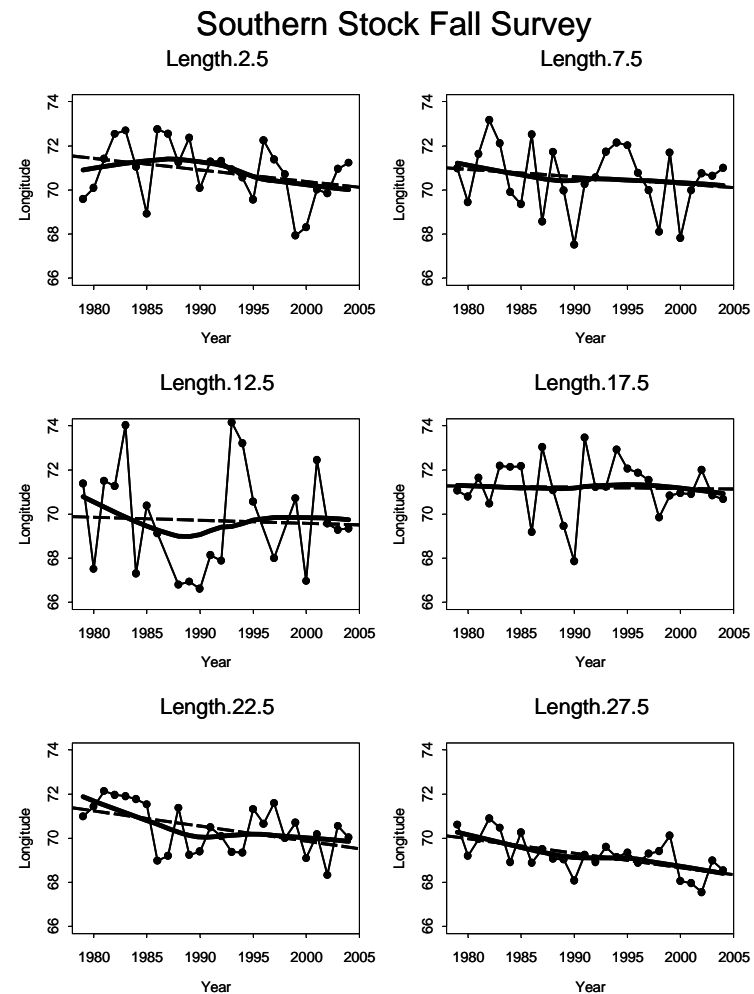
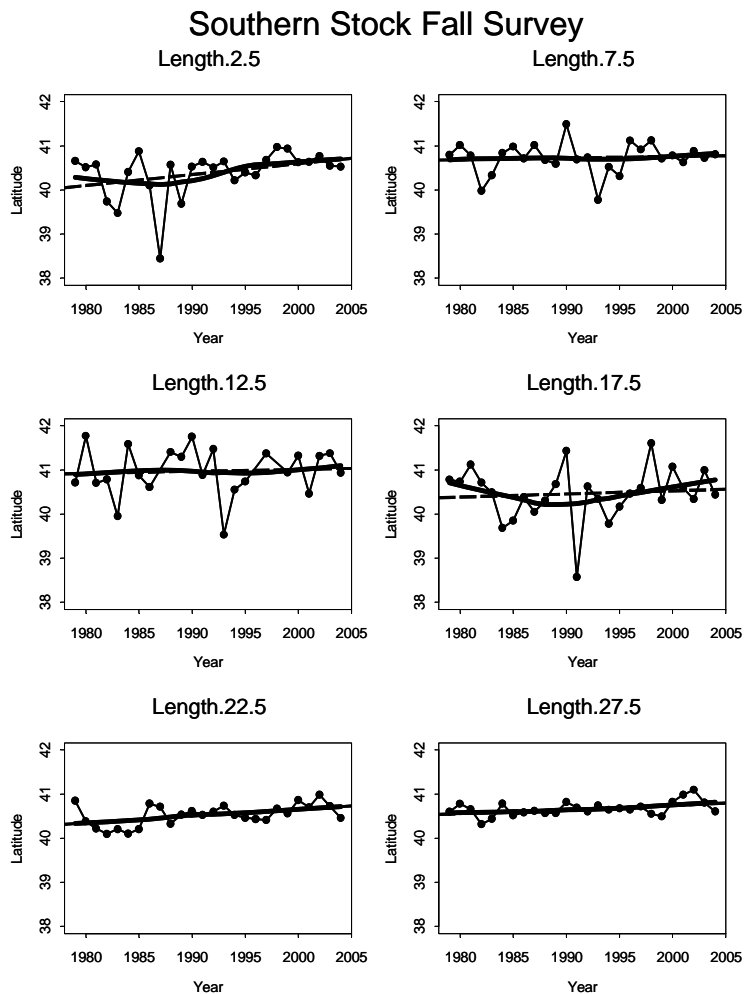


Figure A31. Average position (latitude in left panel and longitude in right) for silver hake in fall bottom trawl surveys in the combined northern and southern stock areas, by size group. Averages are for tows, weighted by catch of the appropriate size group.

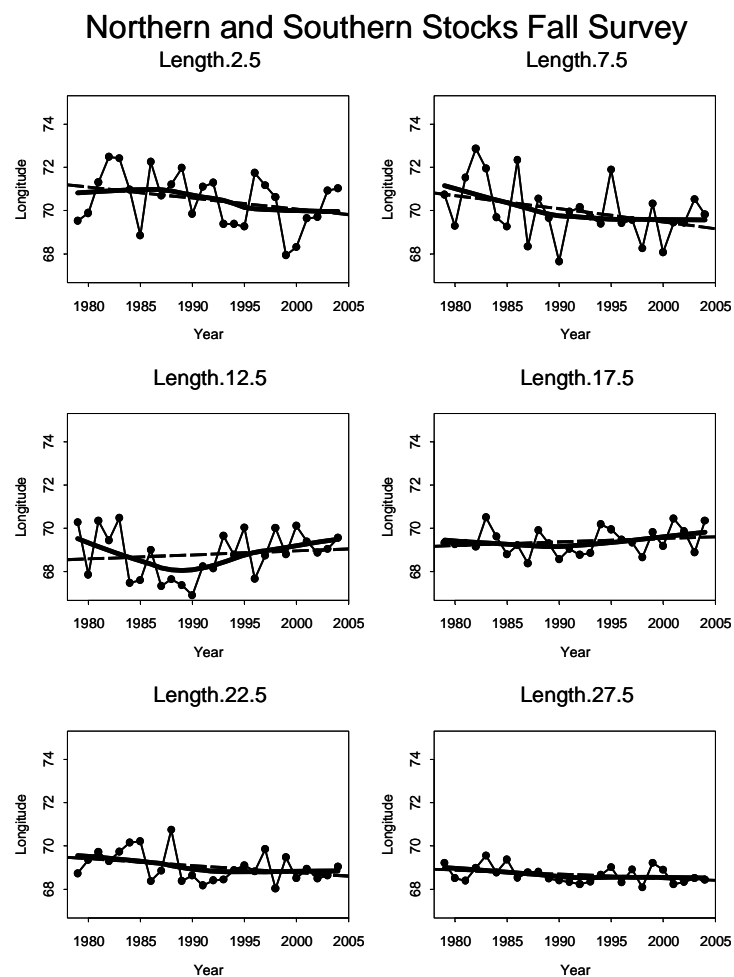
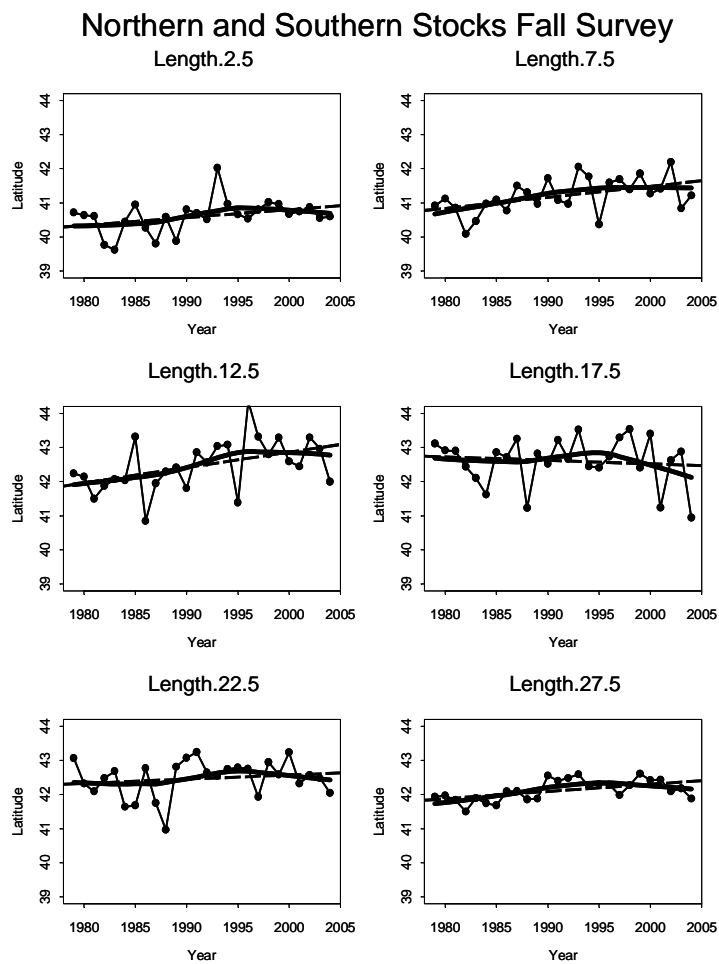


Figure A32. Average position (latitude in left panel and longitude in right) for silver hake in spring bottom trawl surveys in the northern stock area, by size group. Averages are for tows, weighted by catch of the appropriate size group.

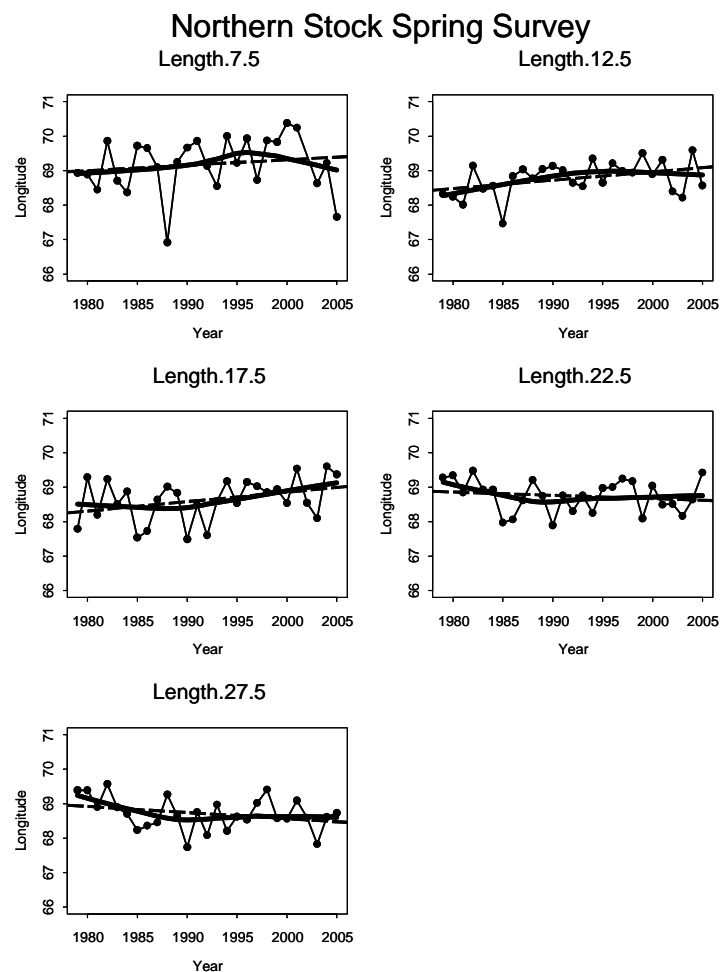
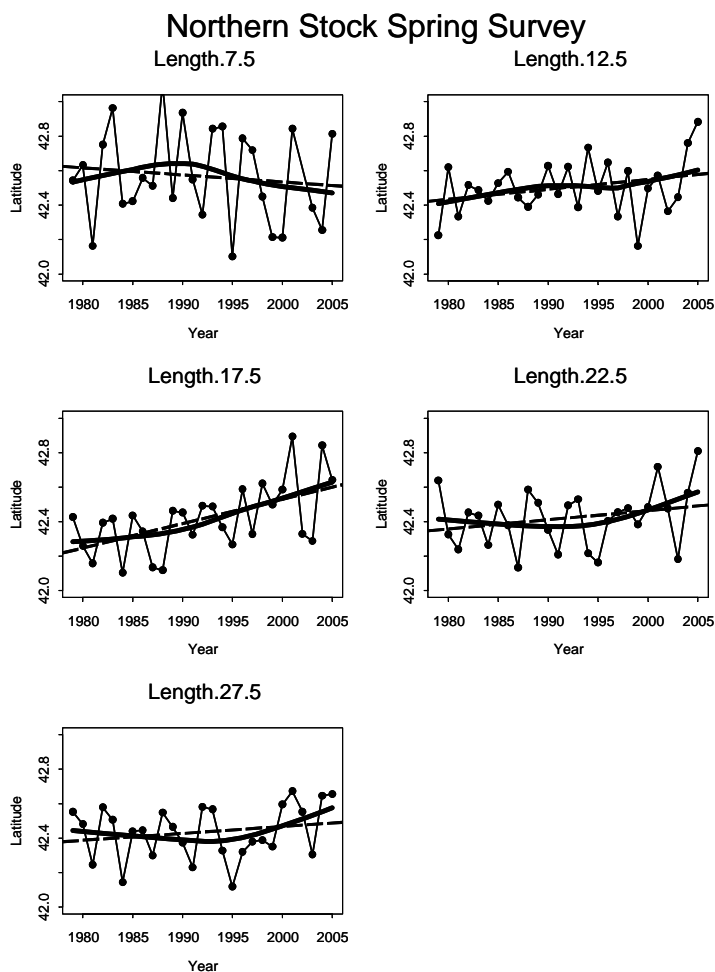


Figure A33. Average position (latitude in left panel and longitude in right) for silver hake in spring bottom trawl surveys in the southern stock area, by size group. Averages are for tows, weighted by catch of the appropriate size group.

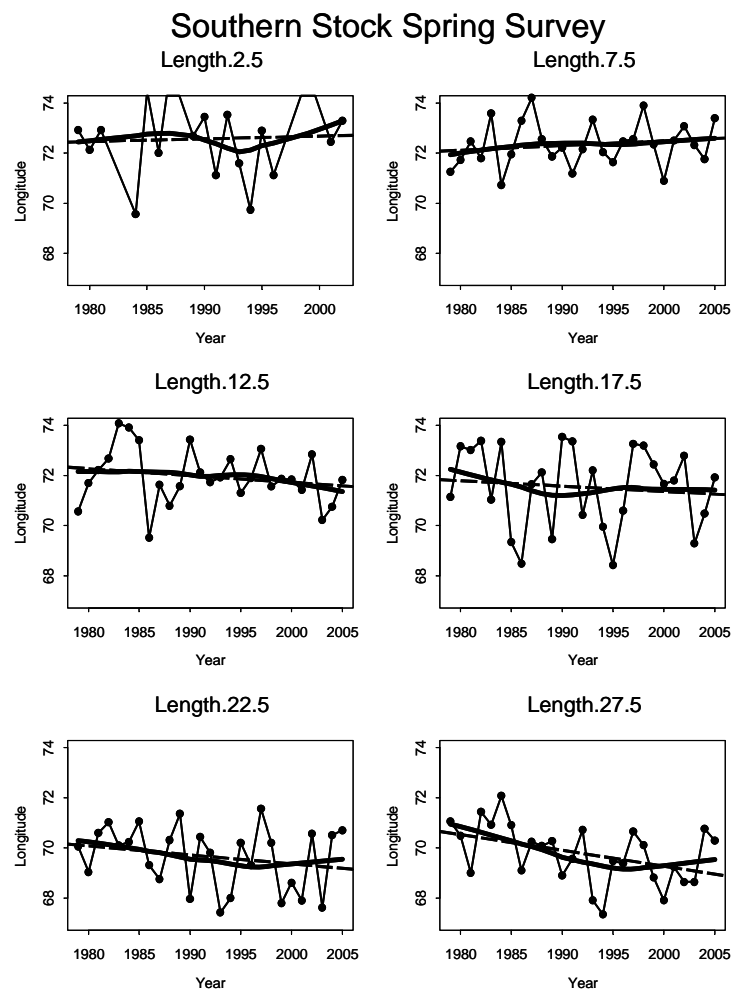
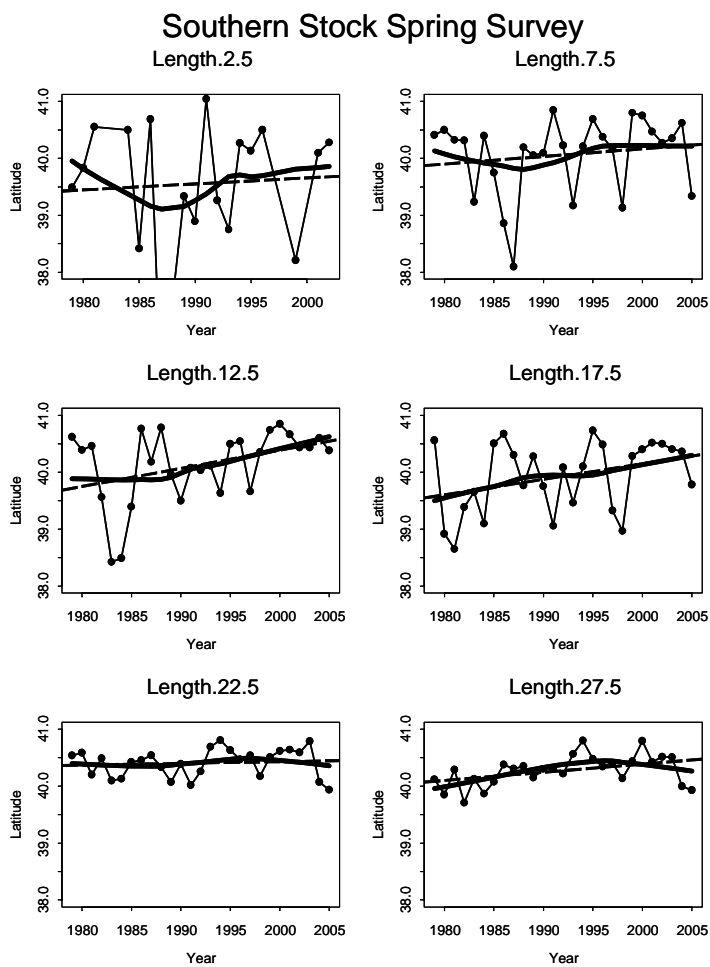


Figure A34. Average position (latitude in left panel and longitude in right) for silver hake in spring bottom trawl surveys in the combined northern and southern stock areas, by size group. Averages are for tows, weighted by catch of the appropriate size group.

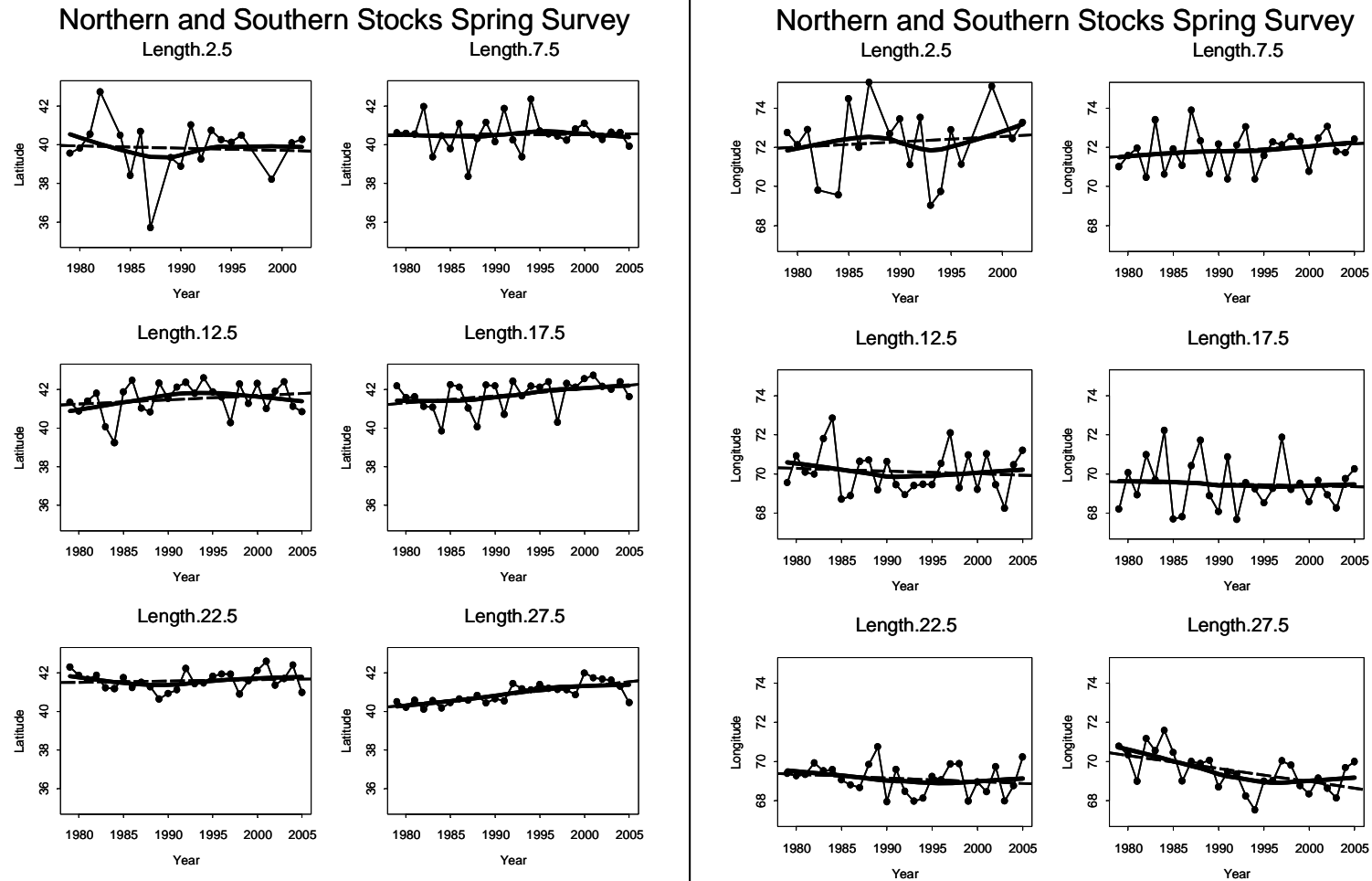
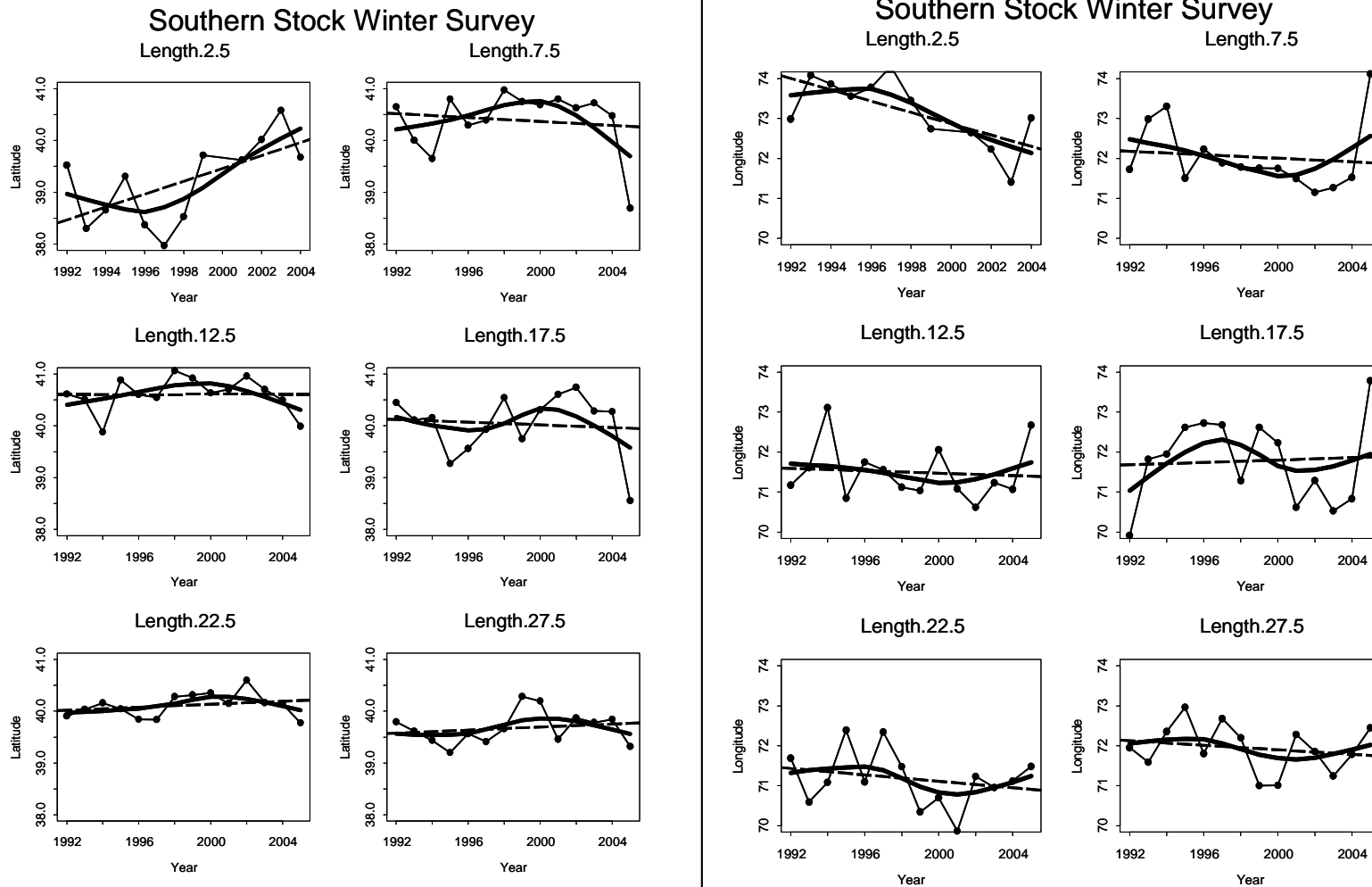


Figure A35. Average position (latitude in left panel and longitude in right) for silver hake in winter bottom trawl surveys in the southern stock area, by size group. Averages are for tows, weighted by catch of the appropriate size group.



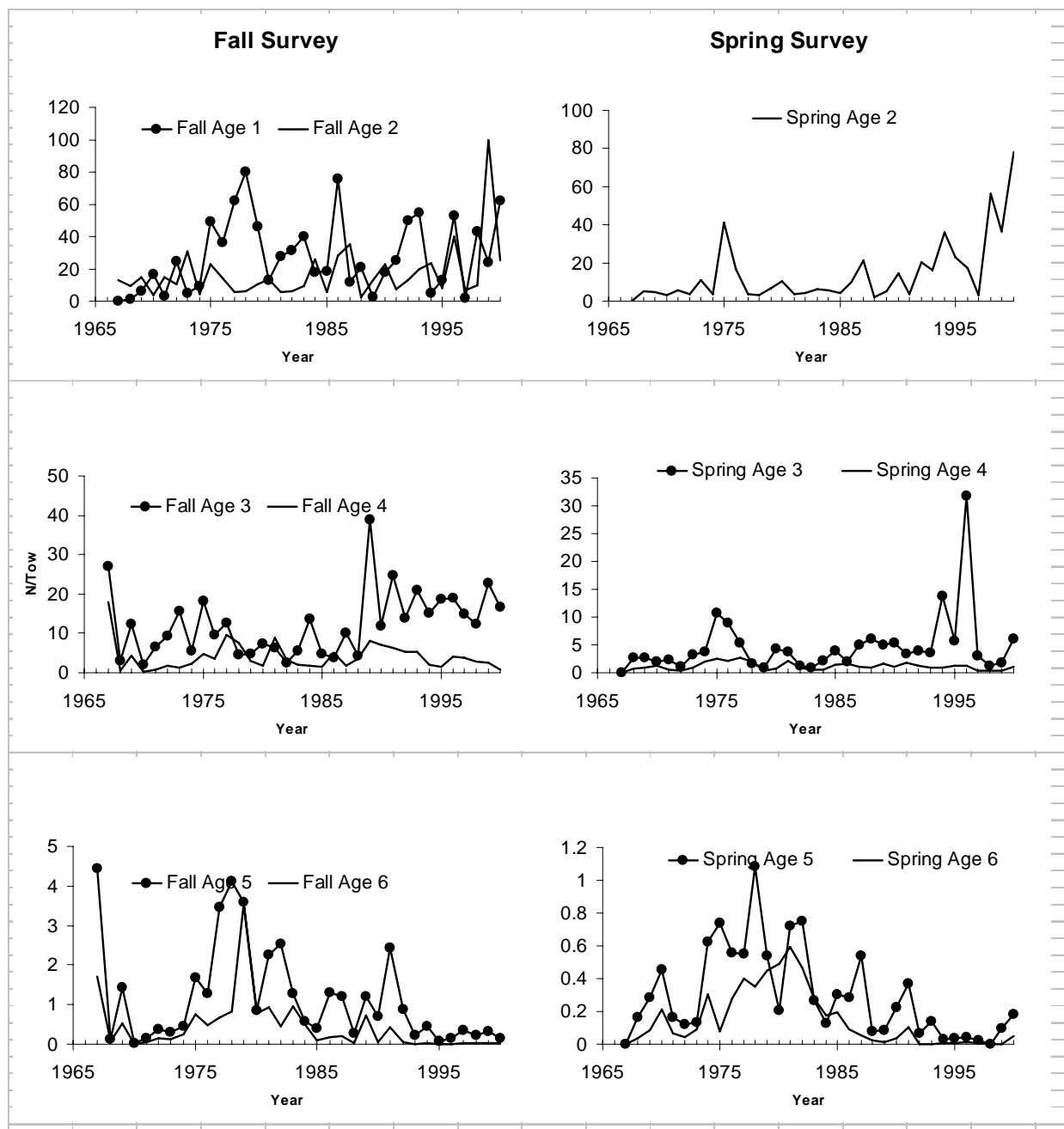


Figure A36. Relative abundance data from Brodziak et al. (2001) for silver hake ages 1-6+ in NEFSC fall and spring surveys. Data for years prior to 1973 were calculated using average age-length keys for spring and fall surveys during 1973-1975.

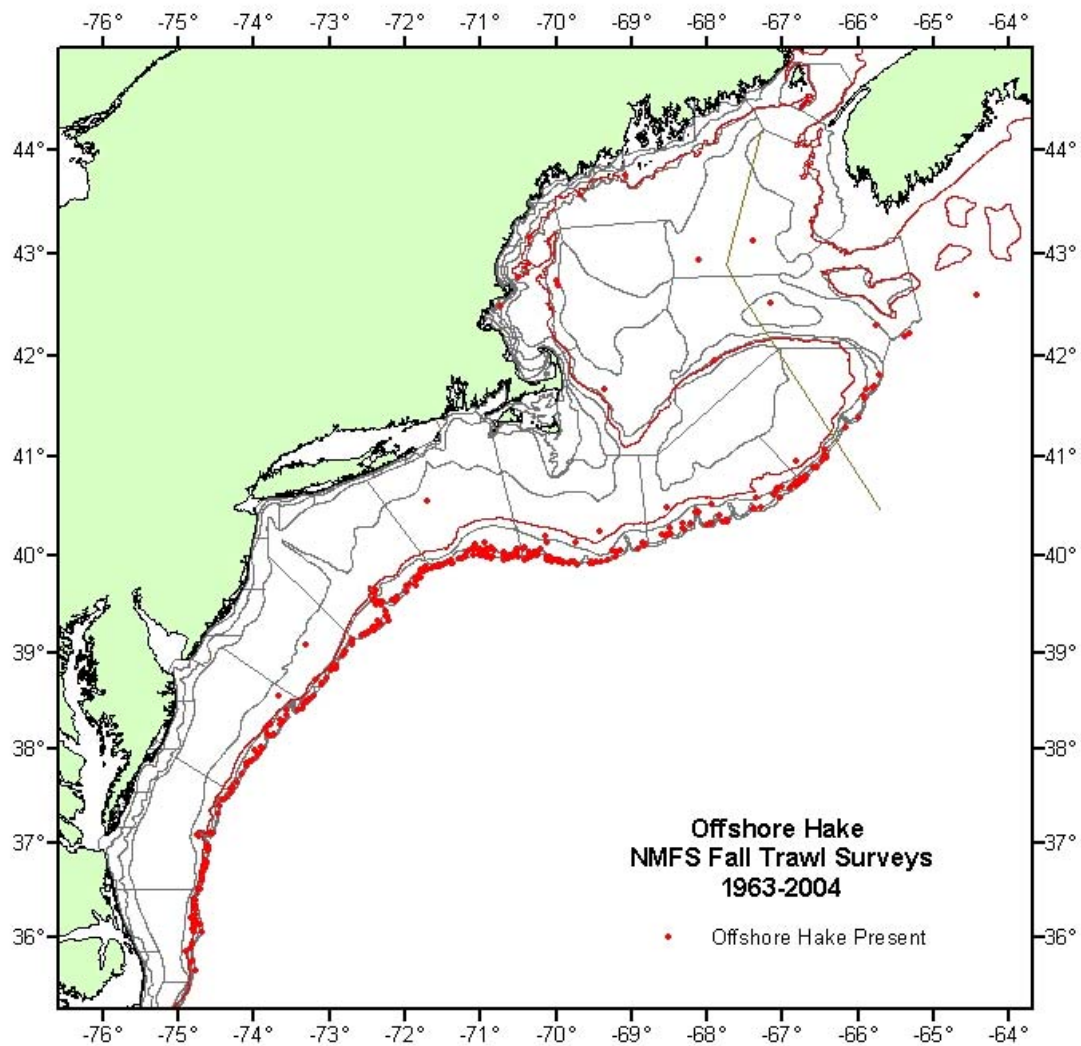


Figure A37. Locations of NEFSC fall bottom trawl survey tows that caught at least one offshore hake during 1963-2004, based all strata that were sampled.

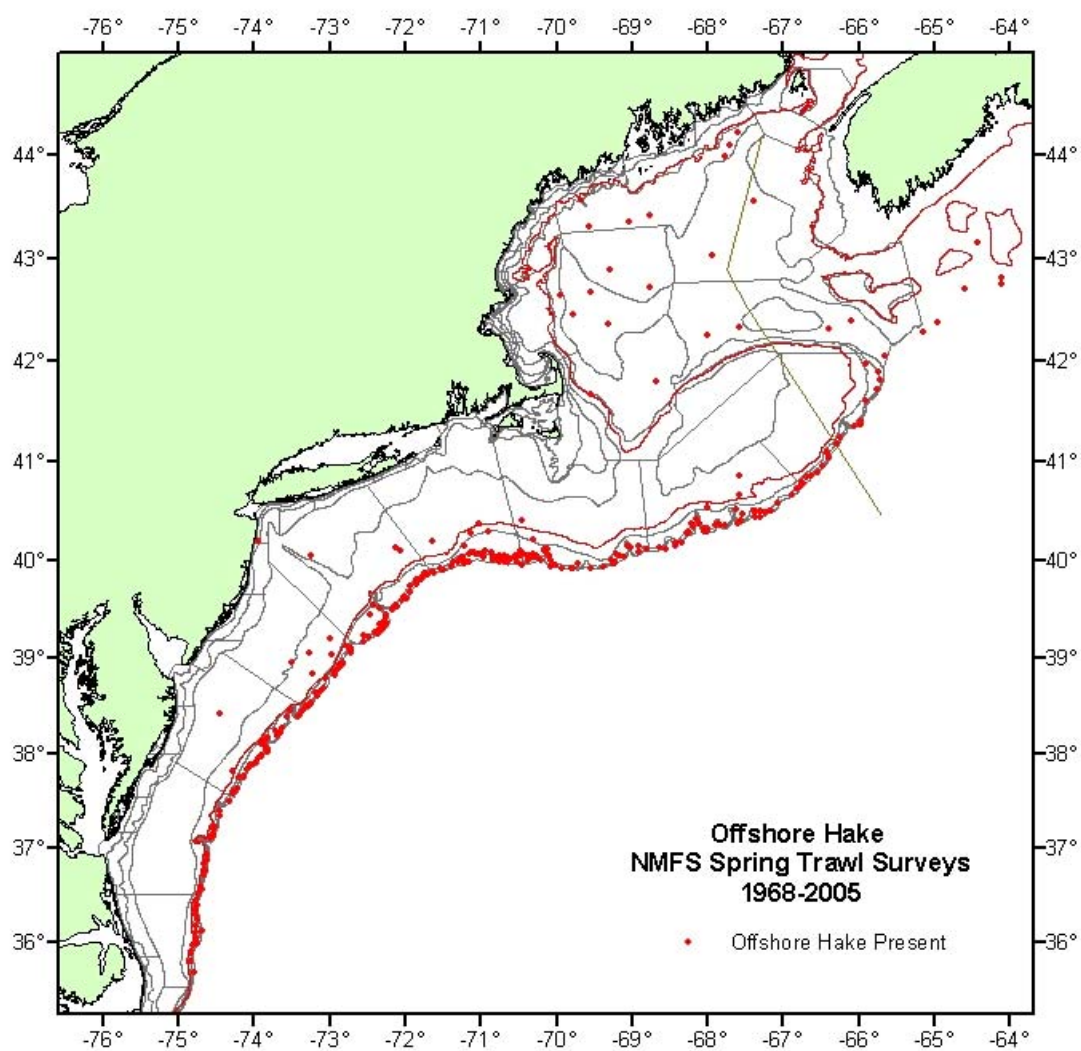


Figure A38. Locations of NEFSC spring bottom trawl survey tows that caught at least one offshore hake during 1963-2004, based all strata that were sampled.

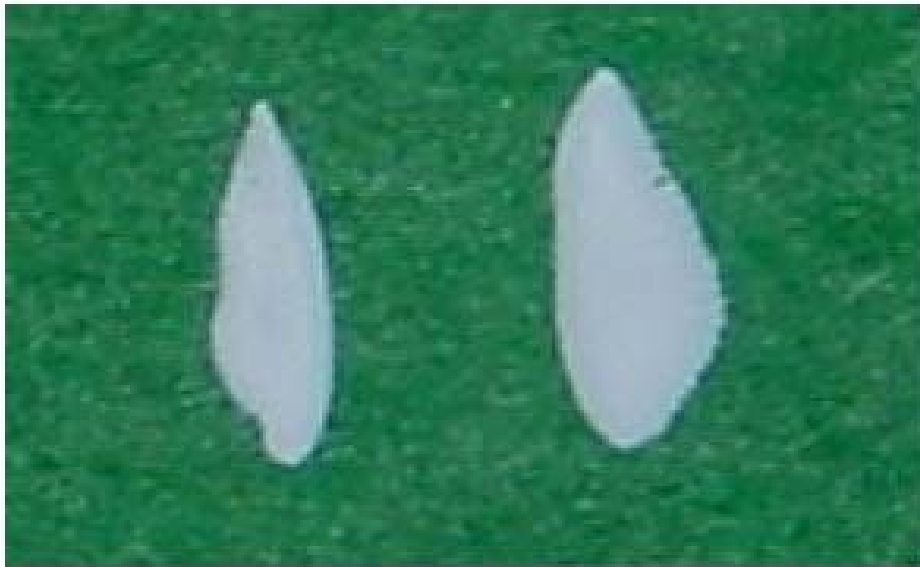


Figure A39. Otoliths from a silver hake (left) and an offshore hake (right). Both specimens were 35 cm TL.

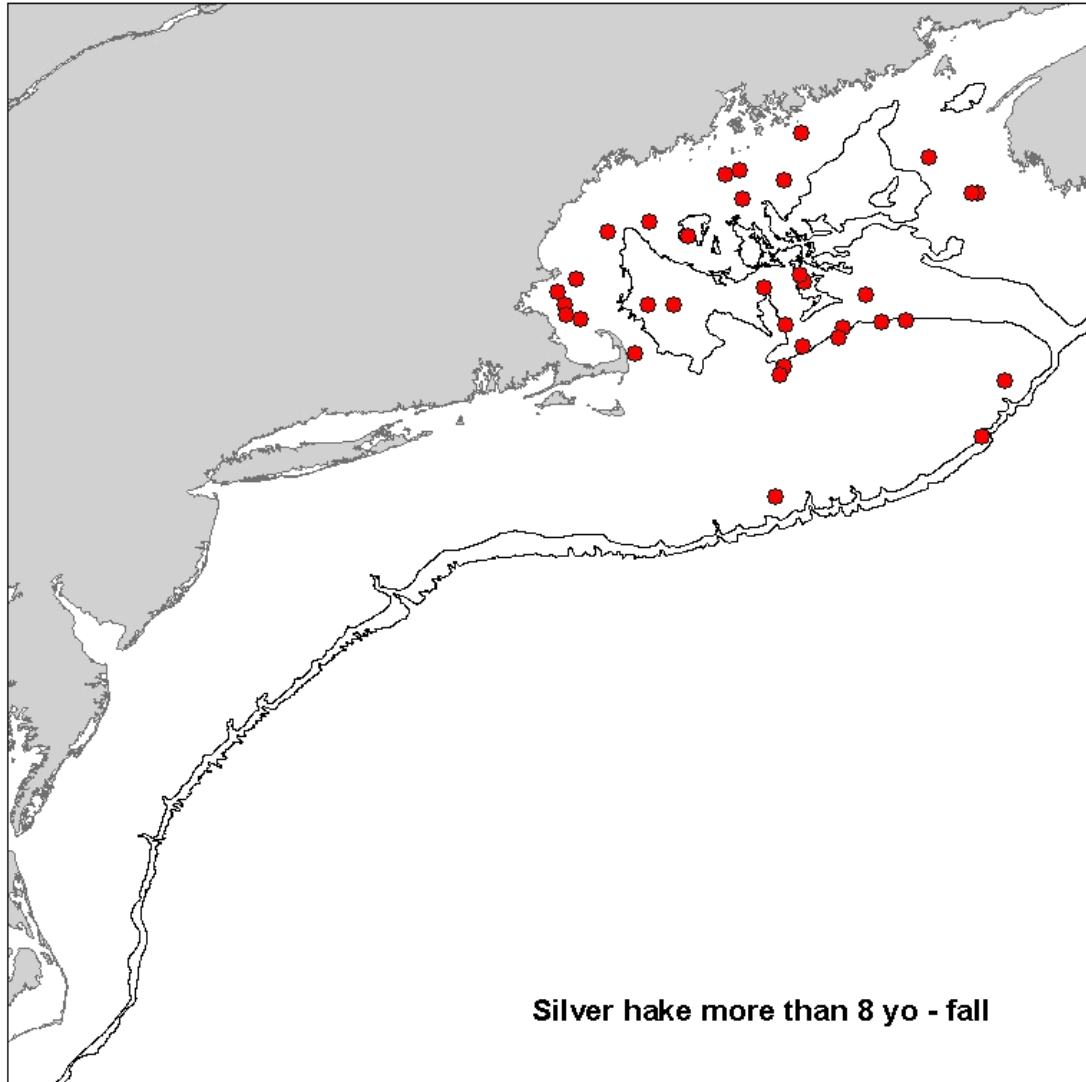


Figure A40. Catch locations for silver hake 8+ y captured during NEFSC fall surveys since 1973.

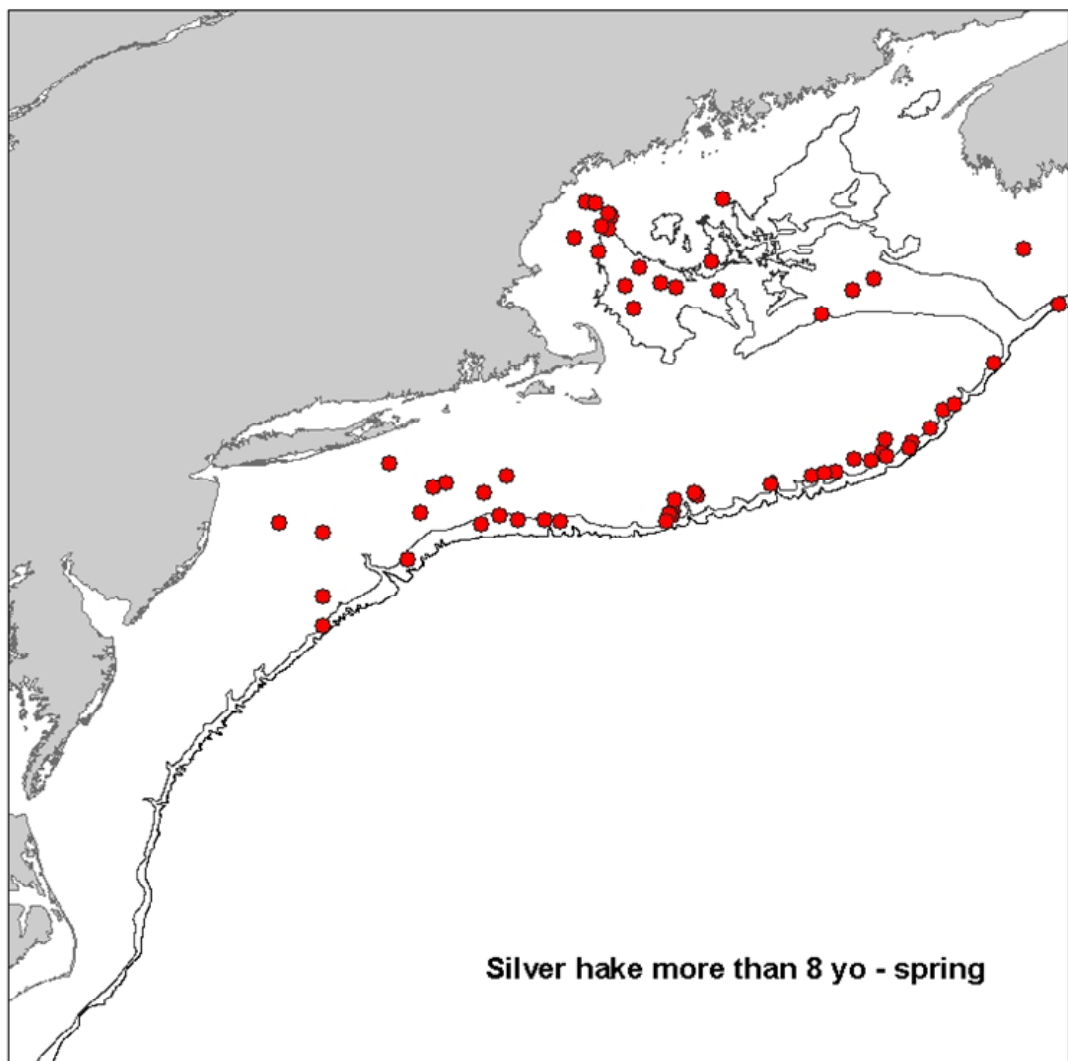


Figure A41. Catch locations for silver hake 8+ y captured during NEFSC spring surveys since 1973.

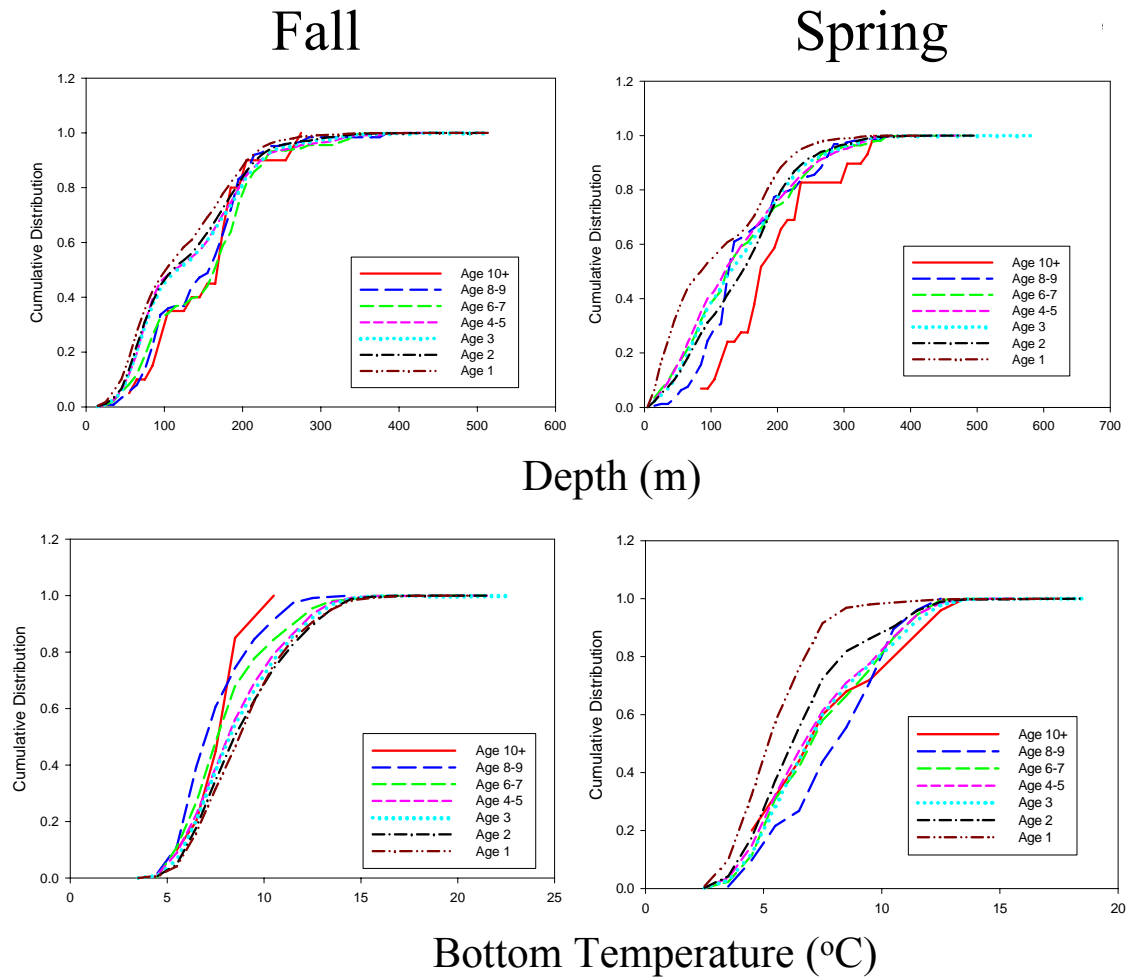


Figure A42. Cumulative depth and bottom temperature distributions for silver hake ages 1-10+ in NEFSC fall and spring bottom trawl surveys.

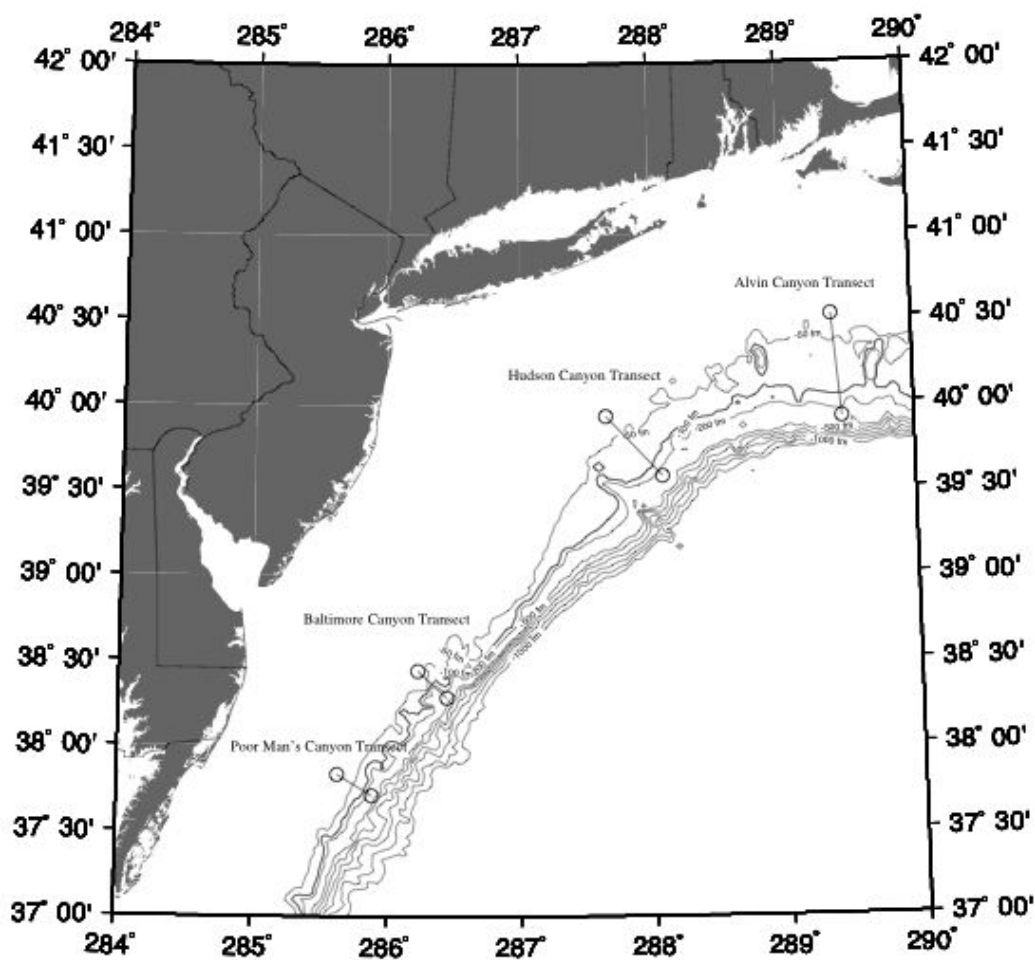


Figure A43. Location of transects for Supplemental Survey sampling. Data from the Baltimore and Hudson canyon transects at depths ≤ 274 m (150 fathoms) were used for silver hake.

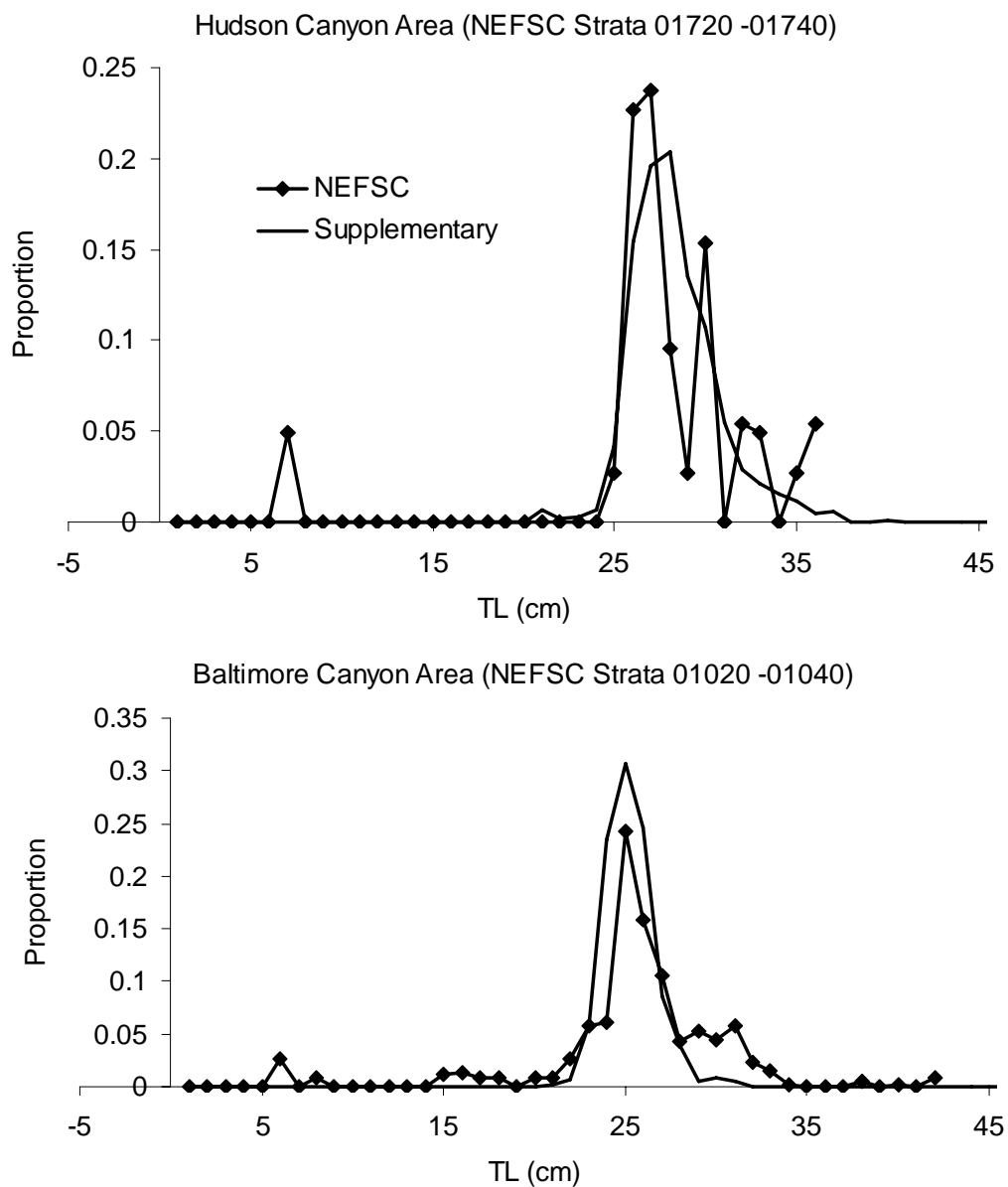


Figure A44. Length composition data for NEFSC and Supplemental surveys during 2004-2005 in the Hudson and Baltimore canyon areas. Data are for 12 tows in each area for the Supplemental survey (both fixed and adaptive stations during day or night were used). NEFSC data are for 14 tows in the Baltimore canyon area and 20 tows in the Hudson canyon area.

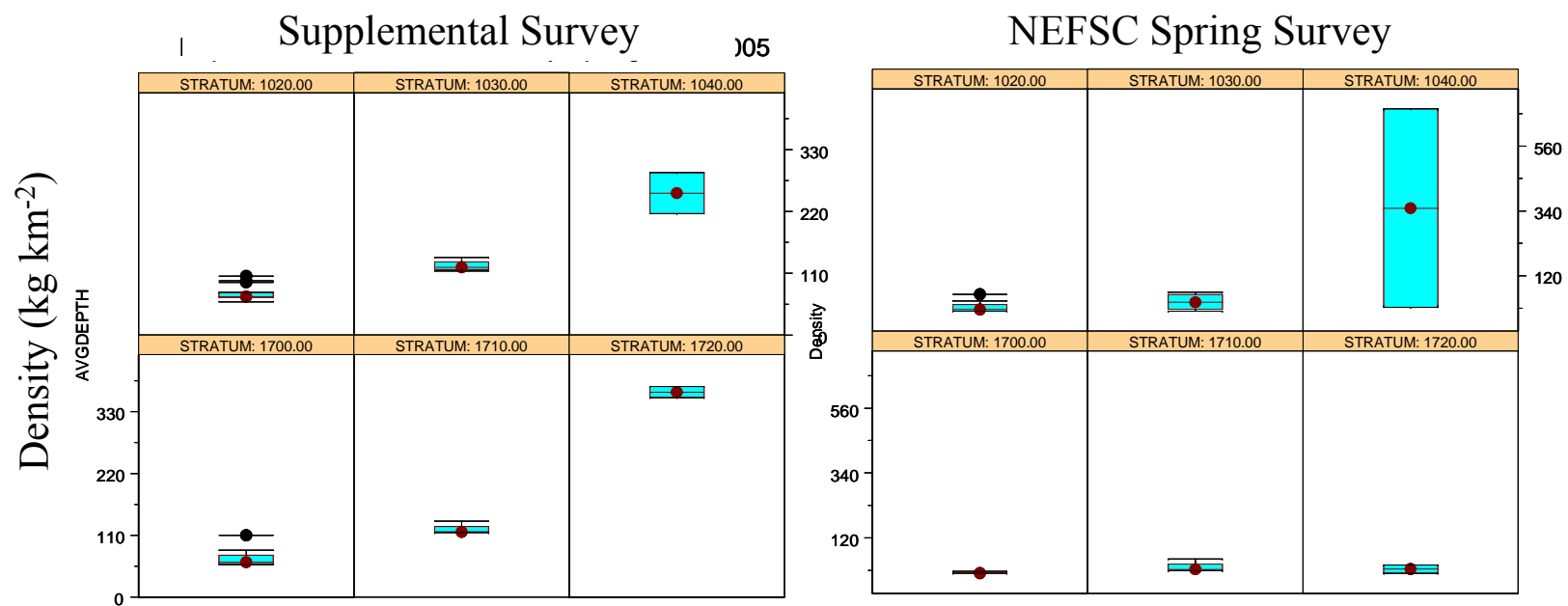


Figure A45. Densities of silver hake measured by the Supplemental and NEFSC spring bottom trawl surveys during March, 2004-2005. Y-axis are the same in all panels.

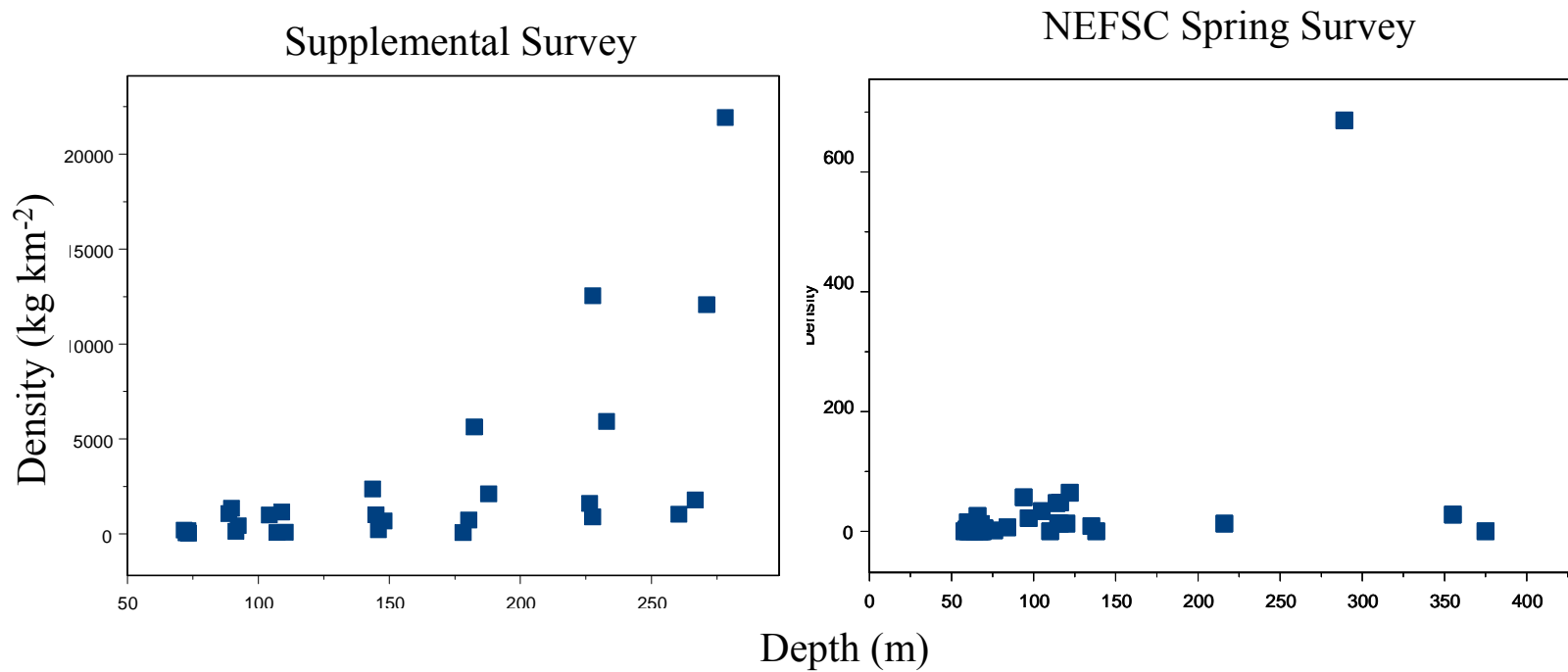


Figure A46. Densities of silver hake measured by the Supplemental and NEFSC spring bottom trawl surveys during March, 2004-2005.

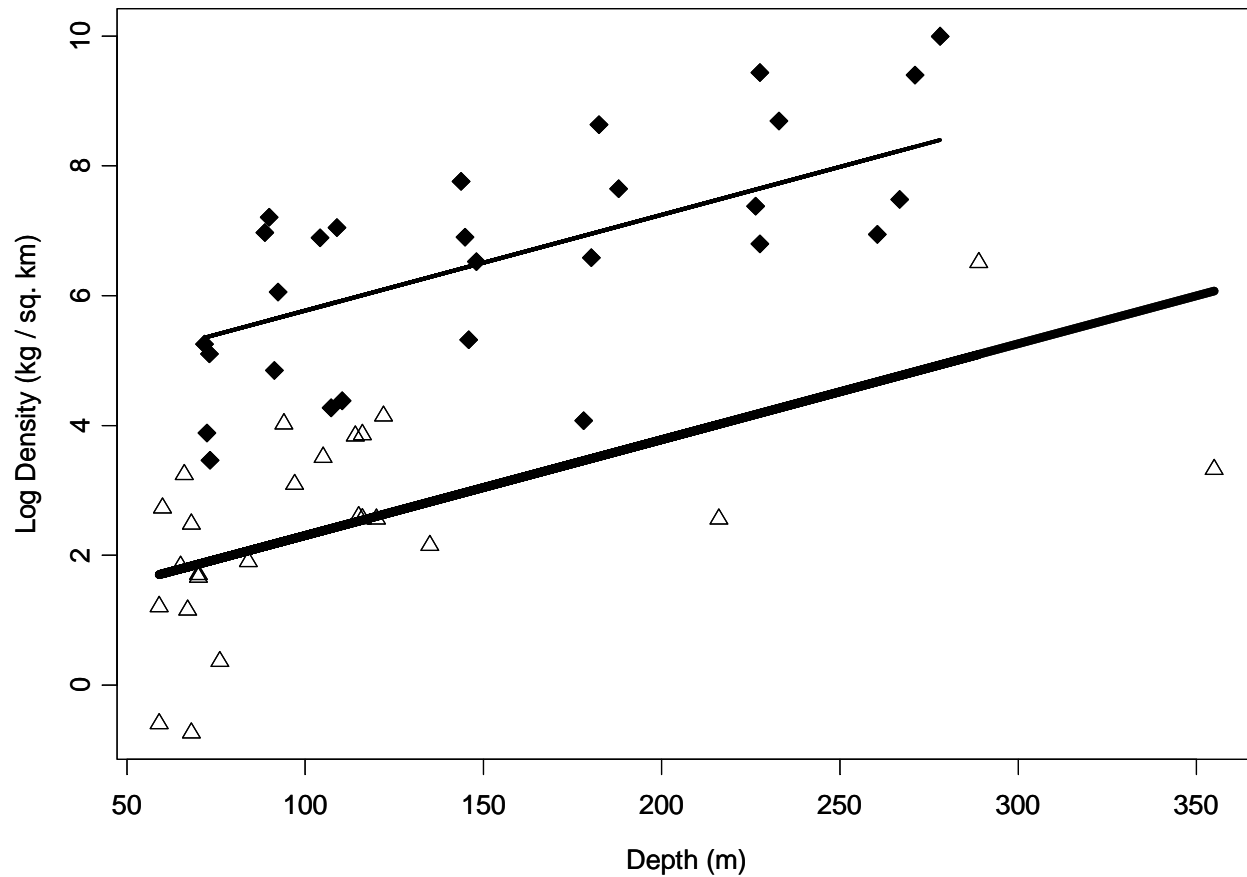


Figure A47. Densities of silver hake measured by the Supplemental (solid diamonds) and NEFSC (open triangles) spring bottom trawl surveys during March, 2004-2005. Lines from the best analysis of covariance model are also shown.

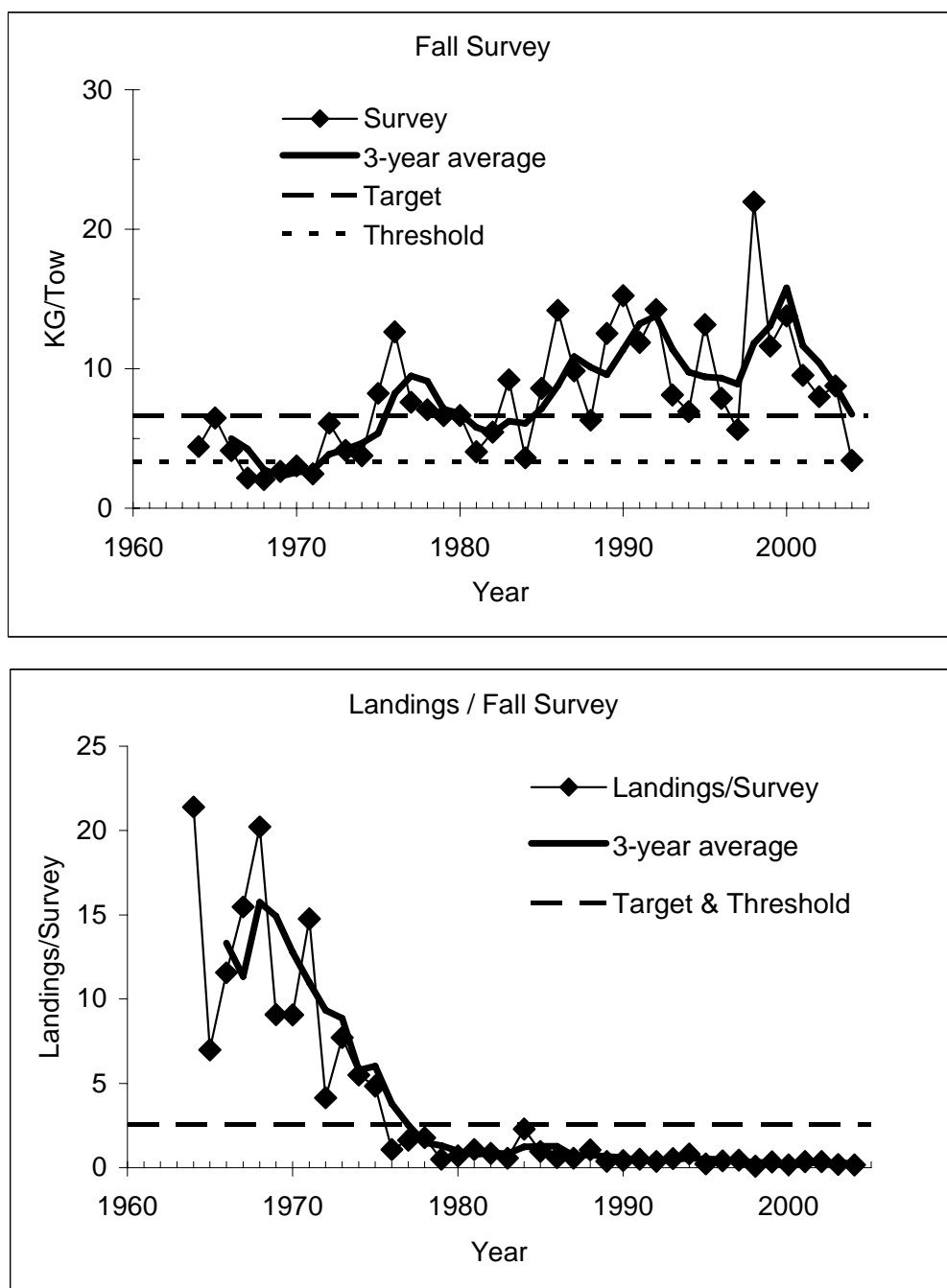


Figure A48. Abundance and exploitation indices for the northern stock of silver hake. Top: fall survey abundance index (delta mean kg/tow, based on consistently occupied offshore strata starting in 1964) with 3-year running average and current reference points for biomass. Bottom: landings/survey (exploitation index) and current reference points.

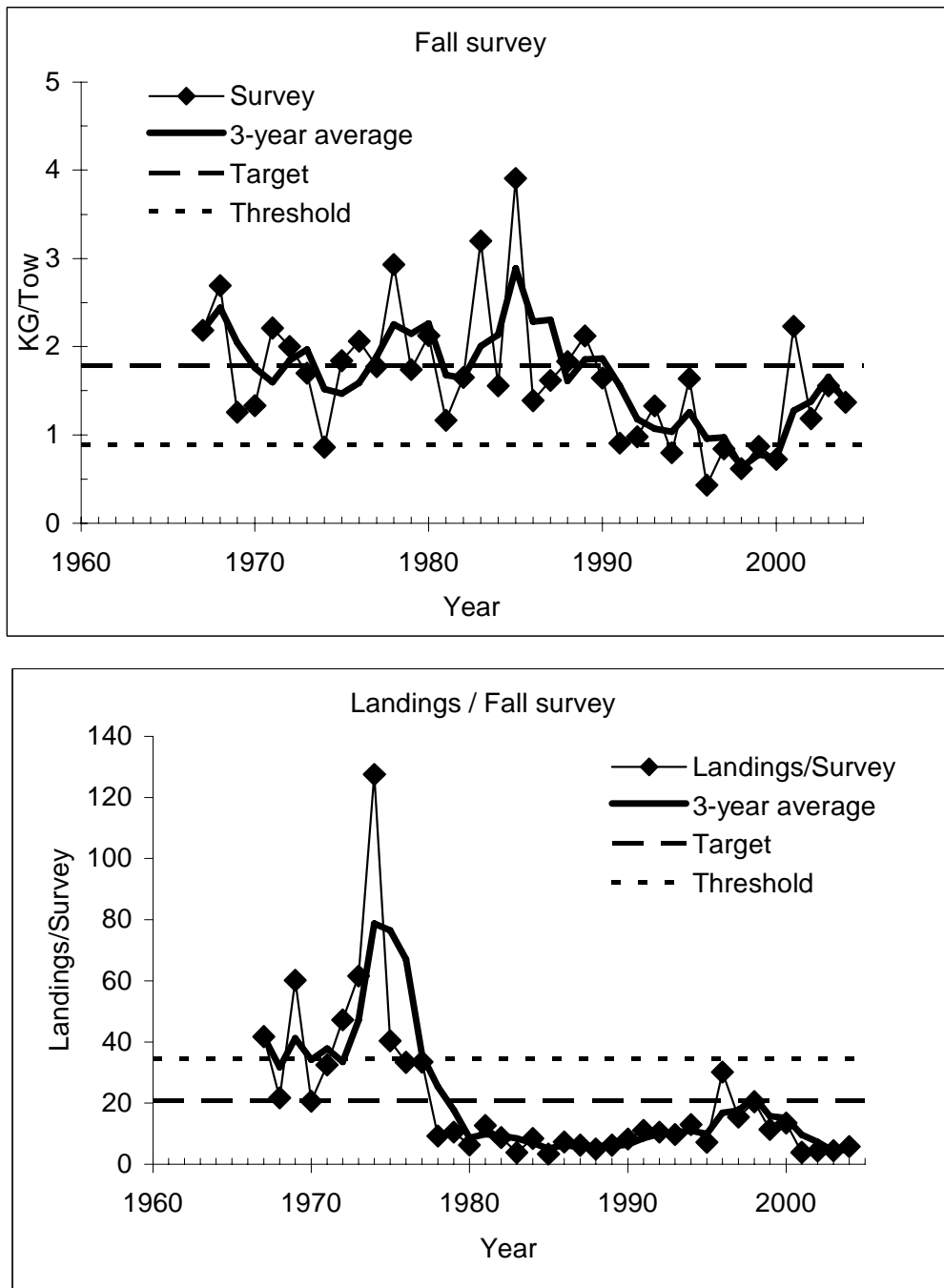


Figure A49. Abundance and exploitation indices for the southern stock of silver hake. Top: fall survey abundance index (delta mean kg/tow, based on consistently occupied offshore strata starting in 1967) with 3-year running average and current reference points for biomass. Bottom: landings/survey (exploitation index) and current reference points.

Figure A50. Lower bounds for fishable biomass and upper bounds for fishing mortality in the northern stock of silver hake during 1964-2004 based on historical landings and fall survey data.

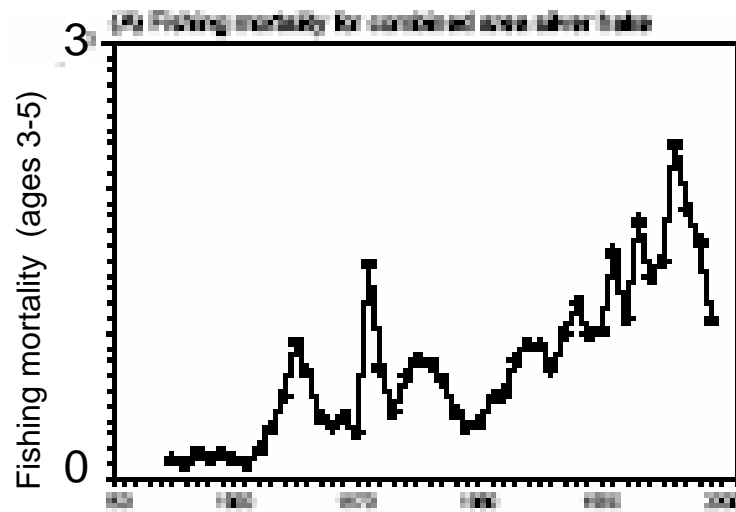
(EDITOR'S NOTE: THIS FIGURE FROM THE WORKING GROUP REPORT HAS BEEN OMITTED. IT WAS NOT ACCEPTED BY THE REVIEW PANEL.)

Figure A51. Lower bounds for fishable biomass and upper bounds for fishing mortality in the northern stock of silver hake during 1964-2004 based on historical landings and fall survey data.

(EDITOR'S NOTE: THIS FIGURE FROM THE WORKING GROUP REPORT HAS BEEN OMITTED. IT WAS NOT ACCEPTED BY THE REVIEW PANEL.)

Estimated fishing mortality and spawning biomass for combined area silver hake from best fit ADAPT model.

(A) Fishing mortality for combined area silver hake



(B) Spawning biomass for combined area silver hake

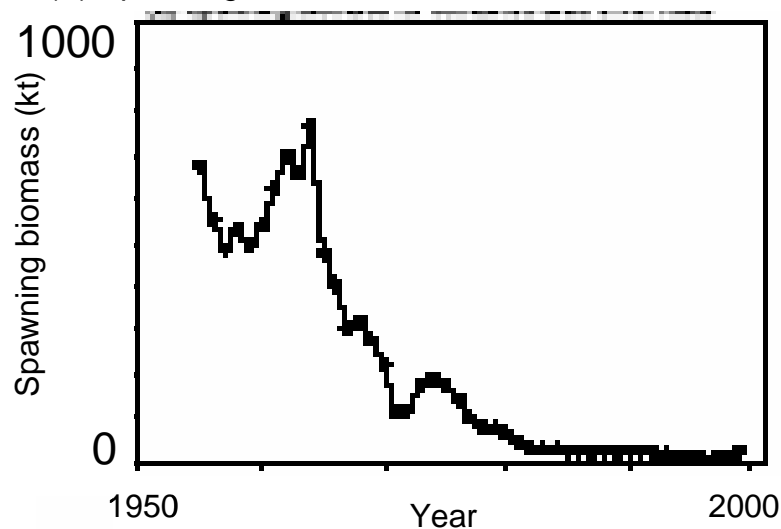


Figure 52. Fishing mortality and spawning biomass estimates for silver hake (northern and southern stock area) from the age structured stock assessment mode in NEFSC (2001).

APPENDIX A1: Stock assessment team members and persons who contributed to the silver hake assessment. “NMFS/NEFSC” stands for the National Marine Fisheries Service / Northeast Fisheries Science Center in Woods Hole, MA.

<u>Name</u>	<u>Organization</u>
F. Almeida	NMFS/NEFSC
J. Brodziak	NMFS/NEFSC
J. Burnett	NMFS/NEFSC
T. Chute	NMFS/NEFSC
L. Col	NMFS/NEFSC
P. Jones	NMFS/NEFSC
L. Jacobson (lead)	NMFS/NEFSC
S. King	Rutgers University (Haskins Shellfish Research Laboratory)
K. Lang	NMFS/NEFSC
J. Link	NMFS/NEFSC
P. Rago	NMFS/NEFSC
K. Sosebee	NMFS/NEFSC
M. Traver	NMFS/NEFSC
S. Wigley	NMFS/NEFSC

APPENDIX A2: Supplemental “Transect” Survey. General information regarding silver hake in the Supplemental “Transect” Survey carried out cooperatively by Industry and the Haskin Shellfish Research Laboratory in Bivalve, NJ. Some calculations (e.g. for “swath areas”) were not discussed by the Joint Working Group or used in the assessment for silver hake.

**Summary of results for whiting from the Supplemental Finfish Survey Targeting
Mid-Atlantic Migratory Species: March 2003 – May 2005**

**Sarah King
Haskin Shellfish Research Laboratory
Rutgers University
Port Norris, NJ**

To date, nine Supplemental Finfish Surveys have been completed. Surveys took place on the F/V Jason & Danielle during the weeks of March 8-12, 2003, May 25-31, 2003, January 24-February 2, 2004, March 4-17, 2004, and May 19-23, 2004. During the weeks of November 15-21, 2004, January 10-22, March 13-23, and May 4-10, 2005 the survey was conducted on the F/V Luke & Sarah. Two transects located near Hudson and Baltimore Canyon were sampled during every survey effort. A transect near Poor Man’s Canyon was sampled during March of 2004 and 2005 and in March of 2005, a transect was sampled near Alvin Canyon (Figure 1). The survey gear, including net, sweep and doors were transferred from the original survey vessel and have remained constant throughout the survey. In November 2004, two new codends were built by the same company and to the same specifications as those used during previous surveys.

To obtain a relative index of silver hake, *Merluccius bilinearis*, from the Supplemental Finfish Surveys Targeting Mid-Atlantic Migratory Species, all calculations have been adjusted to swath area. Swath area measures the relative importance of each sampled depth according to its contribution to total distance along the transect line set perpendicular to the depth contour. Figure 2 shows an example of how the distance along the transect line was allocated to each tow for the calculation of swath area. The calculation projects the swept area of the tow had the net been towed continuously down slope along the transect line, from the shallowest to deepest station, for the distance allocated to each sample depth. This distance is established by the midpoints between perpendiculars dropped to the transect line from the midpoints of each tow (Figure 2).

During the March 2003 survey, silver and offshore hake were not separated and thus, the March 2003 data were excluded from this synopsis. Since the Poor Man's and Alvin Canyon transects were not sampled during every survey effort, data from these transects were also excluded.

Cross-Shelf Biomass By Transect and Survey

The highest overall cross-shelf projected biomasses were observed during March of 2005 along the Hudson and Baltimore Canyon transects. The survey consistently caught, in biomass and abundance, more whiting along Hudson Canyon transect than Baltimore Canyon transect (Tables 1 & 2 and Figure 3).

Swath Projected Biomass By Depth

In order to understand how whiting are distributed both spatially and temporally, the data are broken down by transect, by survey, and by depth. A comparison of depth changes for the 20th, 50th, and 80th percentiles of cumulative catch on each transect is plotted in Figure 4. The 50th percentile, for example, is the depth where the cumulative catch curve reached 50% of the total catch and the 20th and 80th percentiles are confidence interval bands, where cumulative catch reached 20% and 80% of the total catch. Observations show that silver hake are widely distributed across the shelf but are caught most frequently at depths ranging from 80 to 350 m on the Hudson and Baltimore Canyon transects. Whiting are caught as deep as 457 m, the deepest station, though catches tend to be smaller and less frequent at these depths (Table 3 and Figure 4). It is likely that the survey misses a small percentage of the inshore portion of the stock during some surveys. Instances include all of the surveys, but most notably May 2003 (Baltimore), May 2004 (Hudson and Baltimore) (Table 3). Also noteworthy, is the fact that the whiting catches occurred in deeper water more frequently in 2005 than in 2003 and 2004, and it is likely that the survey also misses a small percentage of the offshore portion of the stock.

Silver hake appear to make seasonal inshore/offshore migrations and the population tends to be situated further offshore on the Baltimore Canyon transect than the Hudson Canyon transect (Figure 4). Generally, silver hake are narrowly distributed inshore during the spring surveys (May 2003, 2004, 2005) and migrate further offshore, spreading out over the shelf, during the winter months (March and November 2004 and January 2005). Along the Hudson and Baltimore Canyon transects during the May 2003 and 2004 surveys, silver hake tended to be

most abundant at depths ranging 80-130 m. They spread out over the shelf and move into deeper water during the winter surveys. For example, 60% of the whiting caught along the Hudson Canyon transect occurred at depths of 90-180 m during March 2004, and 210-325 m, in January 2005. Along Baltimore Canyon transect, 60% of the whiting caught occurred at depths ranging from 110-260 m, in March 2004 and 270-360 m, in January 2005 (Figure 4).

Cross Shelf Numbers Per Size Class By Transect and Survey

The size of silver hake caught ranged from 19-52 cm during the March 2004 and 2005 supplemental surveys (Table 4 and Figure 5). More than 95% of the whiting measured during the March surveys ranged from 21-34 cm.

Length-Weight Relationship By Transect and Survey

The von Bertalanffy equation for isometric growth is: $W = aL^b$, where W =weight, L =length, $b=3$, and a is a constant. The length-weight relationships observed for whiting are consistent with this equation and the growth exponent, b , ranged from 3.23-3.30, and R^2 values fell between 68-85% (Figure 6).

Median Size Class Per Depth By Transect and Survey

The 50th percentile size class was determined for each depth sampled for tows with 20 or more measured individuals (Table 5). Within a given survey, the median size of whiting does not appear to vary with depth. In a given survey, the median size of whiting caught on the Baltimore Canyon transect is, on average, 1-2 cm larger than whiting captured on Hudson Canyon transect (Table 5 and Figure 7).

Table 1 (APPENDIX A2). Swath area whiting catch (kg) per tow summed across all tows per transect. This is a theoretical number caught if the net had been towed continuously down slope from the shallowest to the deepest station along each transect.

	Hudson Canyon Transect	Baltimore Canyon Transect
May 2003	240,209.7	17,214.3
January 2004	966,929.5	96,870.9
March 2004	3,057,810.4	256,876.6
May 2004	1,184,289.6	187,153.3
November 2004	5,218,371.8	799,376.9
January 2005	3,041,186.9	499,071.9
March 2005	9,445,397.0	1,130,256.1
May 2005	5,215,401.3	625,998.6

Table 2 (APPENDIX A2). Swath area projected total abundance of measured whiting across all tows for each survey. The multiplication of these numbers and the percentages in Table 4, provide the reader with the project number of whiting per size class (March 2004 and 2005, only).

	Hudson Canyon Transect	Baltimore Canyon Transect
May 2003	1,171,783.4	76,713.8
January 2004	68,783,310.9	815,642.1
March 2004	646,675,951.2	12,803,011.3
May 2004	24,839,510.8	1,111,541.7
November 2004	4,176,326,937.9	1,211,781,610.3
January 2005	3,332,306,046.2	235,738,849.4
March 2005	14,076,324,593.3	894,659,210.2
May 2005	1,663,613,791.5	41,528,449.4

Table 3 (APPENDIX A2). Percentage of total whiting catch (kg) at each depth. Dashes represent stations that were not sampled. For each transect, the depth with highest percentage of whiting caught per transect is highlighted. H=Hudson Canyon transect, B=Baltimore Canyon transect.

Target Depth (m)	<u>Mar-04</u>		<u>Mar-05</u>	
	H	B	H	B
73.15	3.38	2.00	1.47	0.32
82.30	-	-	-	5.96
91.44	26.14	13.73	12.08	5.30
100.58	1.28	-	1.09	2.56
109.73	9.23	11.15	3.42	2.63
128.02	10.75	-	2.22	-
146.30	17.88	24.47	2.64	18.64
164.59	8.94	3.00	-	-
182.88	3.61	0.66	11.75	10.98
204.83	-	6.10	8.29	-
228.60	7.51	4.45	14.62	16.59
250.55	2.01	11.11	14.22	3.23
274.32	9.15	19.67	12.68	25.48
320.04	-	2.35	13.93	5.80
365.76	0.12	1.30	0.69	2.33
387.71	-	-	-	-
411.48	0.00	0.02	0.88	0.19
457.20	0.00	-	0.02	-

Table 4 (APPENDIX A2). Cumulative size-frequency distribution of whiting across all tows, reported as a percentage of total abundance. For each transect, the size with highest percentage of whiting caught per survey is highlighted. H=Hudson Canyon transect, B=Baltimore Canyon transect.

Length (cm)	<u>Mar-04</u>		<u>Mar-05</u>	
	H	B	H	B
18	0	0	0	0
19	0	0.001	0	0
20	0	0	0.32	0
21	0.03	0.77	3.30	0.12
22	0.64	0.41	17.47	0.90
23	1.59	0.15	29.53	4.82
24	7.62	0.76	22.59	21.85
25	15.55	3.28	14.55	30.54
26	18.76	15.52	5.82	26.77
27	14.83	19.71	4.15	7.57
28	15.41	22.51	0.85	5.02
29	8.16	13.32	0.41	0.75
30	8.29	11.52	0.15	0.85
31	3.89	3.95	0.03	0.74
32	1.09	2.42	0.02	0.01
33	1.68	2.29	0.01	0.01
34	0.80	1.20	0.13	0.0004
35	0.60	1.18	0.003	0.003
36	0.48	0.33	0.01	0.01
37	0.15	0.56	0.02	0.01
38	0.32	0.03	0.45	0.02
39	0	0.07	0.0003	0
40	0.10	0.03	0	0.001
41	0.002	0	0	0
42	0	0	0.01	0
43	0.002	0	0.17	0
44	0	0	0.01	0
45	0	0.01	0.001	0
46	0	0	0	0
47	0	0	0	0
48	0	0	0	0
49	0	0	0	0
50	0	0	0	0
51	0	0	0	0
52	0	0	0.001	0
53	0	0	0	0

Table 5 (APPENDIX A2). Dashes represent tows where less than 20 whiting were measured or station was not sampled.

Target Depth (m)	<u>Mar-04</u>		<u>Mar-05</u>	
	H	B	H	B
73.15	26.7	28.1	24.9	26.1
82.30	-	-	-	24.9
91.44	27.0	28.9	25.0	25.3
100.58	26.9	-	25.1	24.8
109.73	26.3	-	25.2	25.0
128.02	-	-	26.8	-
146.30	27.1	28.1	23.9	24.2
164.59	25.6	28.6	-	-
182.88	25.5	-	22.5	24.1
204.83	-	27.2	23.0	-
228.60	25.6	26.5	22.6	24.4
250.55	25.0	27.7	23.3	24.4
274.32	27.8	27.3	23.1	24.8
320.04	-	28.8	23.5	24.9
365.76	-	27.9	25.6	25.0
387.71	-	-	-	-
411.48	-	-	24.5	24.8
457.20	-	-	-	-
Overall	26.4	27.4	23.0	24.7

Figure 1 (APPENDIX A2). Location of transects sampled during Supplemental Survey cruises.

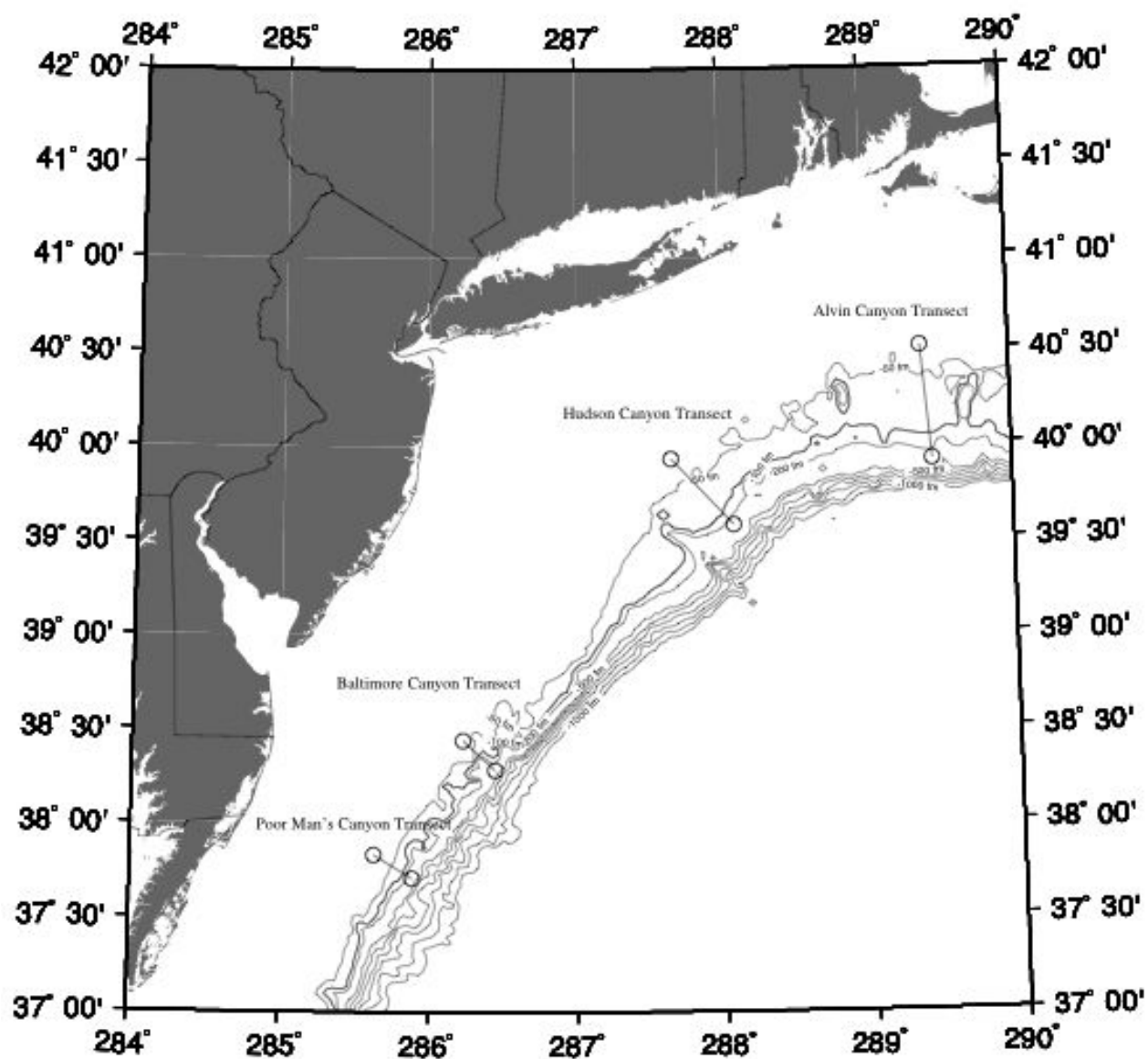


Figure 2 (APPENDIX A2). Swath distance for tows 1, 2, and 3, taken near a transect, showing the distance allotted to each tow had it actually been taken along the transect line.

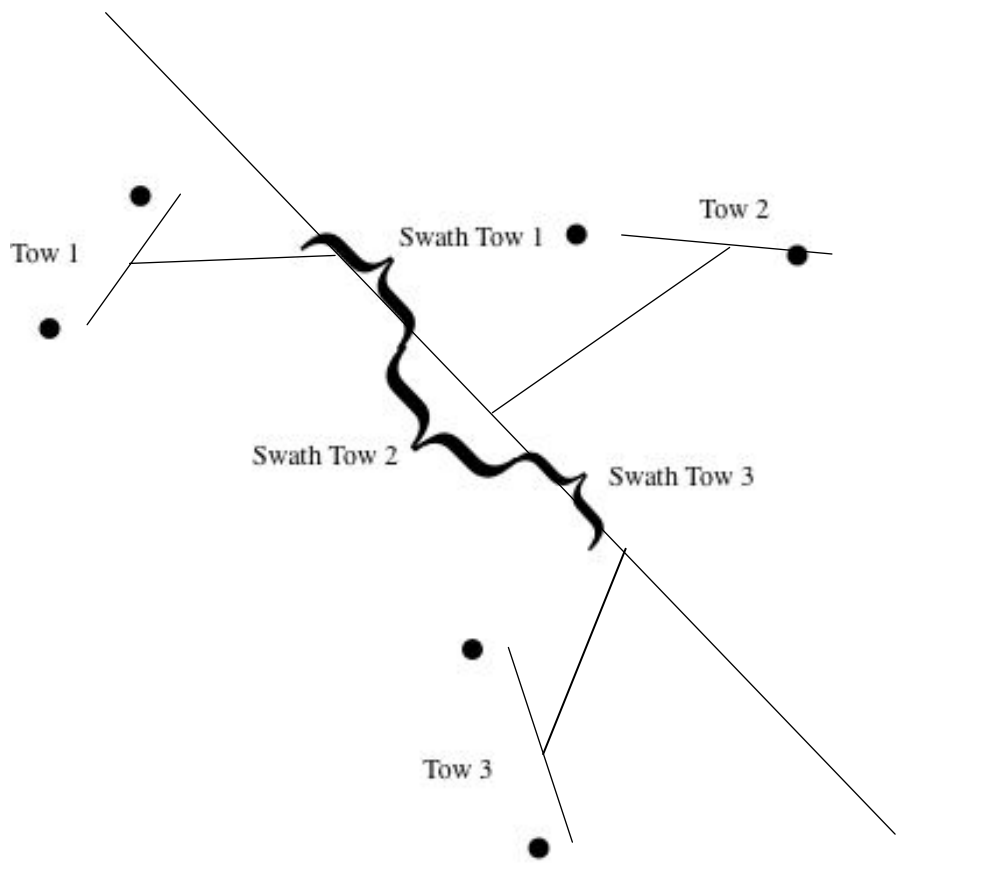


Figure 3 (APPENDIX A2). Projected biomass and abundance of whiting along each transect for each survey. In order to display all of the data on the same figure, there is an axis break in projected biomass. Logarithmic axis scaling was necessary in order to plot the projected abundances from all of the surveys on one figure.

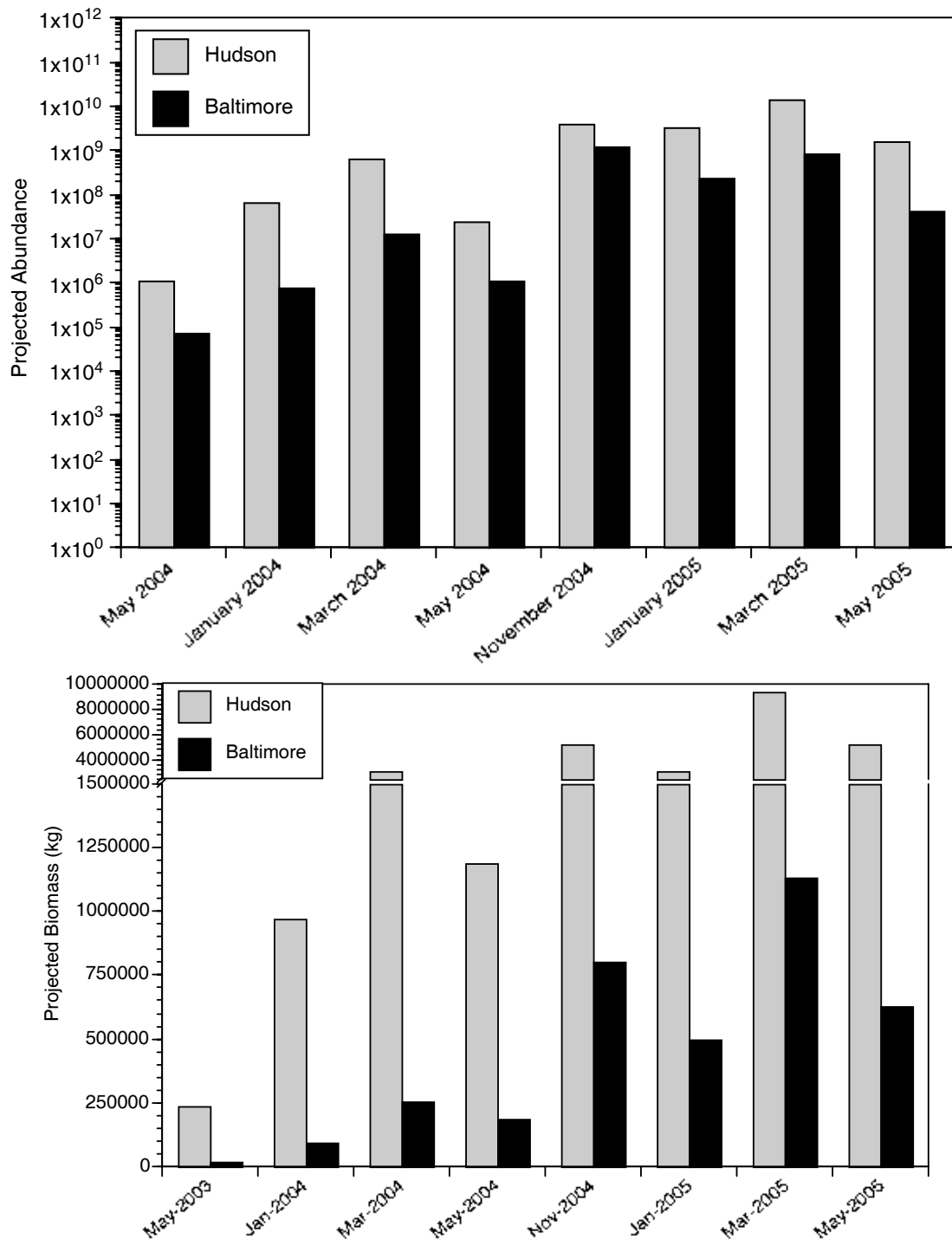


Figure 4 (APPENDIX A2). Comparison of changes in depth for the 20th, 50th, and 80th percentiles of cumulative catch during all surveys completed through May 2005. To calculate the percentiles, swath area catch (Table 2) was cumulated from the shallowest to the deepest station on each transect. The 20th percentile, for example, is the depth where the cumulative catch curve reached 20% of the total catch.

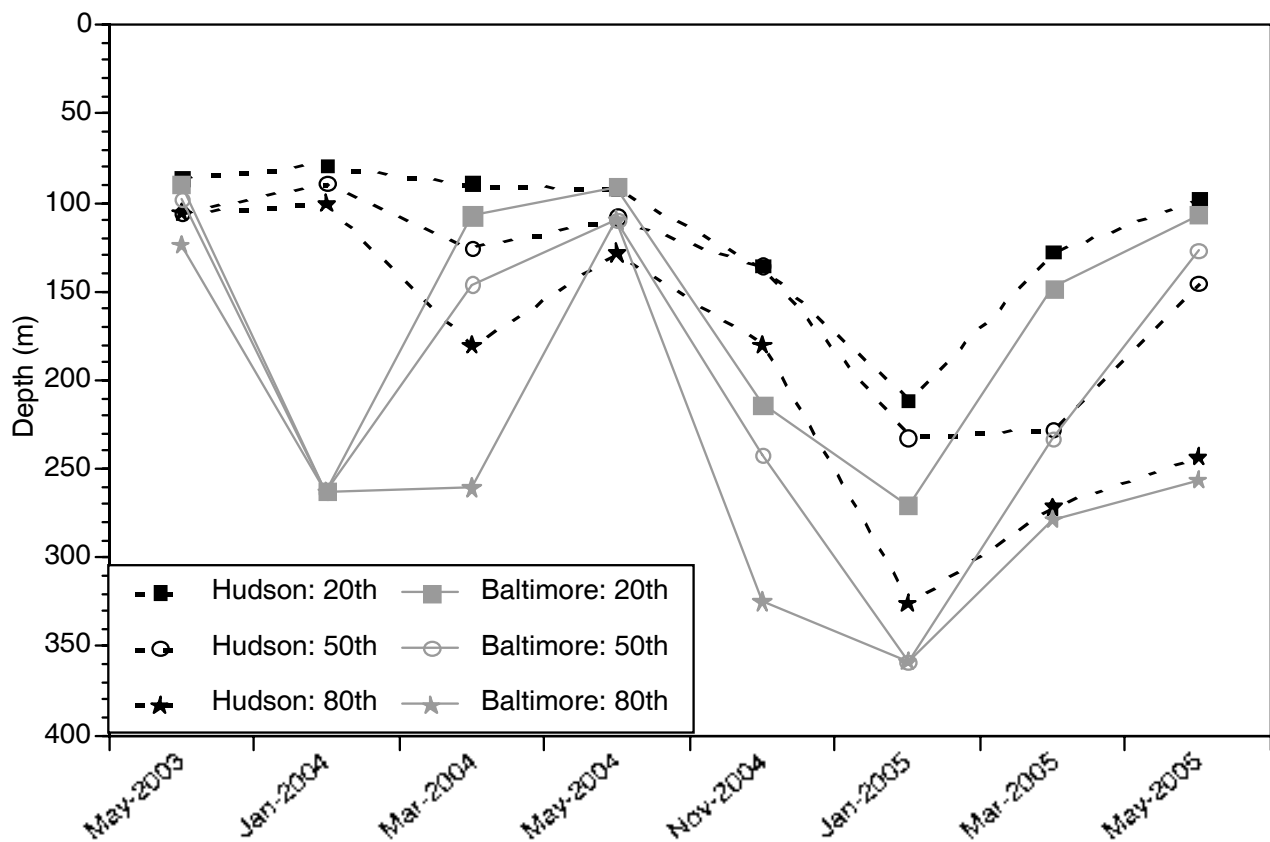


Figure 5 (APPENDIX A2). Projected number of whiting per size class across all tows for the March 2004 and 2005 surveys. Tow size frequencies were corrected to the number caught per km² swept area. Tows were then normalized to swath distance along the transect and the abundances were summed across all tows for each transect. Logarithmic axis scaling was necessary in order to plot data from all surveys on one figure. Note: zeros were not plotted.

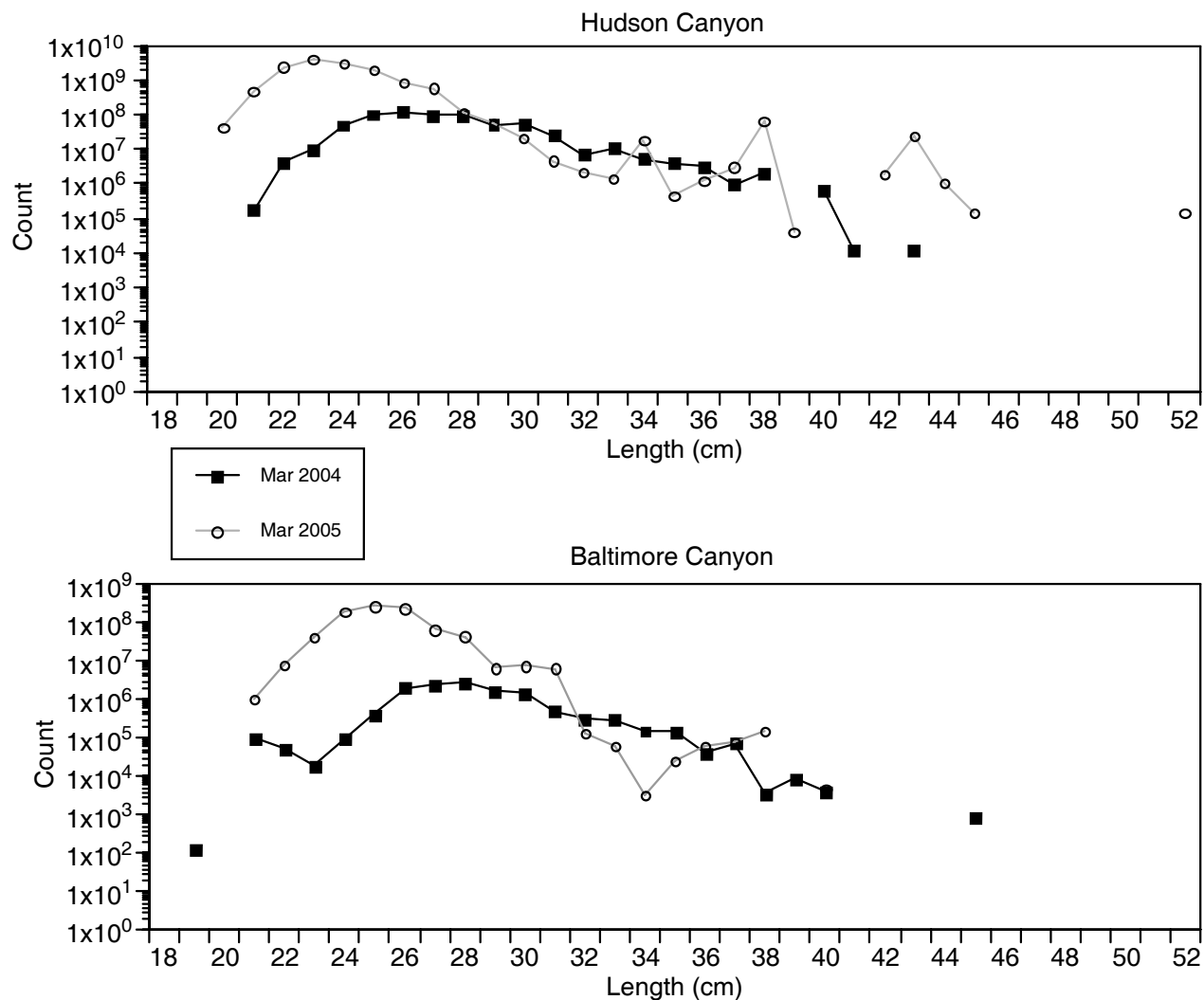


Figure 6 (APPENDIX A2). Relationship between length and weight for silver hake measured in March 2004 and 2005. $f(x)=\text{weight}$, $x=\text{length}$.

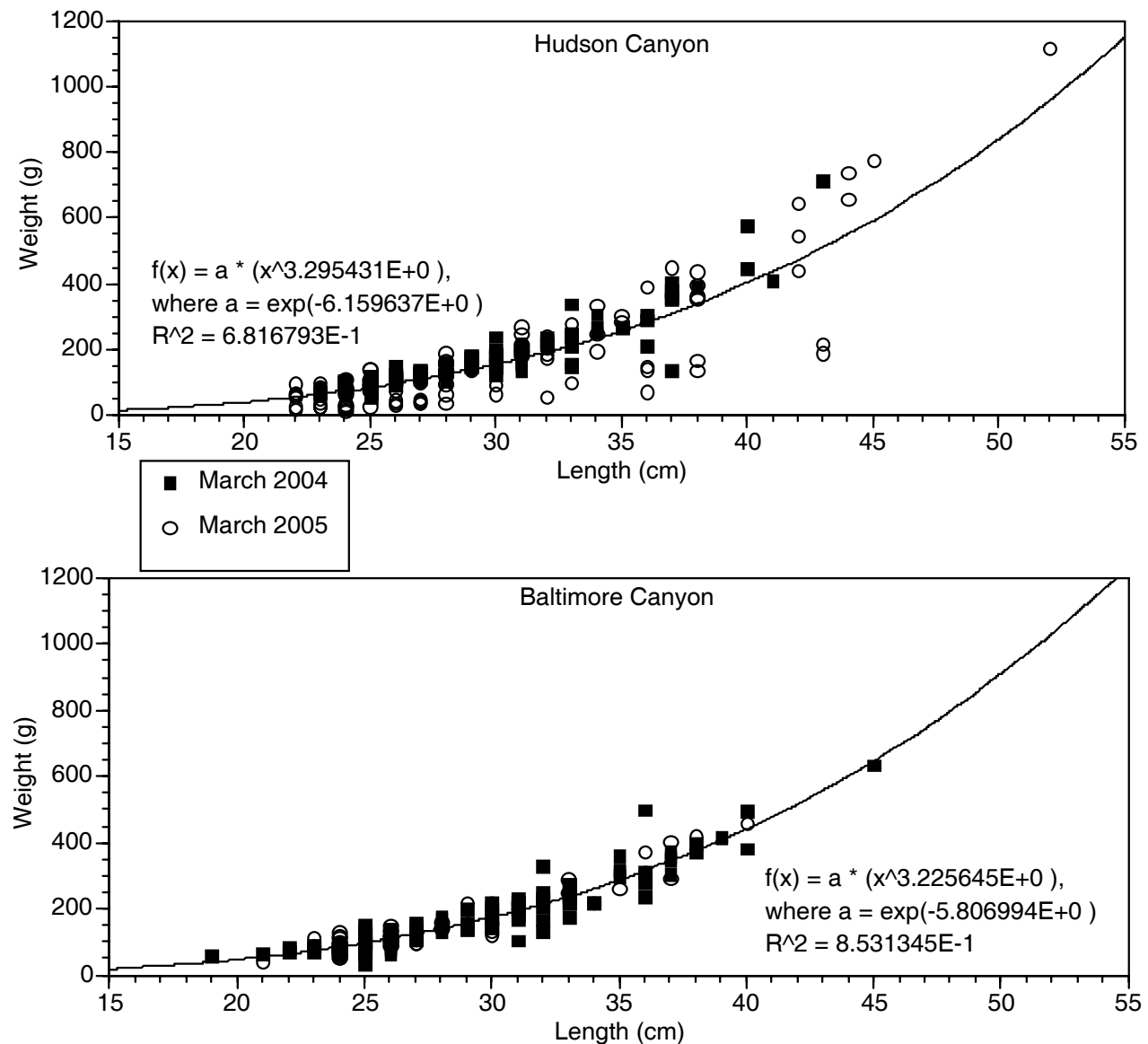
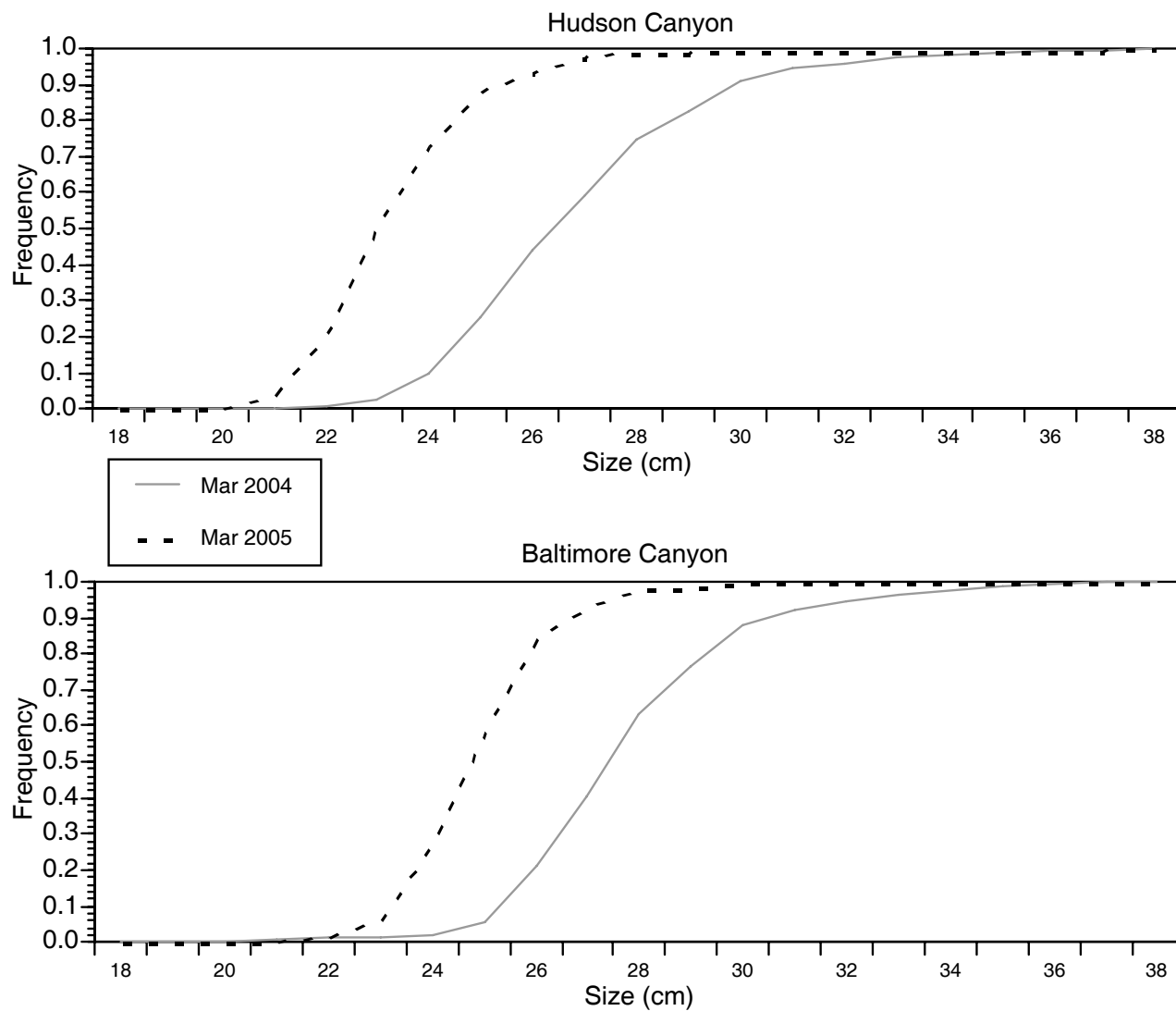


Figure 7 (APPENDIX A2). Cumulative size frequency for whiting from the March 2004 and 2005 surveys.



APPENDIX A3: Chairman and Rapporteur's Report from Working Group Meeting.

Silver Hake WG Meeting, Oct. 24-28, 2005.

Truncation of Older Fish

A concern was raised that the relatively high spawning stock biomass and low fishing mortality estimates for silver hake are inconsistent with the recent truncation of older, larger fish in the commercial and NMFS survey data. The Working Group also noted that the change in total mortality needed to account for the observed decline in age structure seems unrealistic. The intense fishing effort by foreign fleets during the 1960s and 1970s may have caused such a decline in age structure, but it was noted that recently the age structure does not show expansion despite decades of lower fishing effort. It was observed that the truncation of the older silver hake started in the mid 1980s when survey doors changed, and it was recommended that gear comparisons be reexamined by length.

Ageing error was discussed as one possibility for the recent lack of older silver hake, since sectioning methods and age readers have changed. Attempts to re-age old fish from archived otoliths show that new ages average one to two years younger than original ageing. However, these slight biases do not seem to explain the age truncation seen in the survey, and the older fish in the earlier part of the survey time series also correspond to larger fish than are currently being observed.

The Working Group also discussed the possibility that the older fish in the historical NMFS data could have been mis-identified as offshore hake. In the NMFS spring survey, the distributions of older silver hake roughly corresponded to offshore hake distributions. However, it is not likely that the aged fish are mis-identified since the otoliths are distinct between the two species, and no mis-identified otoliths have been found in recent years. The older fish also seem to fall on the same age-length growth curve as the young silver hake, indicating that they are most likely not offshore hake, although growth curves for offshore hake were not examined. The commercial sample data are not aged. The commercial catch is not sorted by species and may include offshore hake, especially from the area along the shelf edge where offshore hake are often found.

The decrease of large silver hake in commercial landings was discussed by the Working Group, and it was noted that the closure of areas for lobster pot fisheries could be affecting catch composition since large fish were historically caught in these areas. The recent decrease in silver hake landings can be attributed to catch limits implemented in 2001.

Stock Structure

A question was raised about whether the northern and southern silver hake stocks are in fact distinct. The two stocks are within close proximity to each other, and it is thought that some exchange exists between the two areas. However, there is currently no new evidence to refute the current stock structure assumed in management.

The Working Group noted that silver hake recruitment seemed strong in both stocks. Concern was expressed that estimates of fishable biomass of silver hake in the NMFS surveys is

far less in the southern stock than in the northern stock. Several potential explanations were discussed including greater fishing efforts in the south, less thorough coverage of silver hake habitat by NMFS surveys in the south, especially in deep waters, and possible exchange between the Scotian Shelf and the northern stock.

Survey and Commercial Data Uncertainty

Concern was expressed that the catchability of silver hake in the NMFS survey could be variable since silver hake are known to come off the bottom during the day. The point was also made that the decreased catchability during the day could be a net avoidance issue, since the species is a visual feeder. However, the NMFS survey design assumes that strata are sampled randomly during day and night, and catchability is not biased over the time series.

Commercial discard estimates were calculated on a trip basis, but the Working Group discussed examining changing target species between tows. Due to variability between years, small sample sizes, and the belief that target species during a trip would not frequently change, discards were estimated on a trip basis. A recommendation was made to also include catches that are entirely discarded, as well as some fisheries with low discard rates but large landings such as large mesh groundfish. Despite the low discard ratio of silver hake in the groundfish fishery, these discard estimates should be included due to the substantial catch volume.

Depth was found to be a more significant predictor of large silver hake distribution than temperature, and concern was expressed that the NMFS survey does not thoroughly cover deeper habitat. The Working Group noted that interactions should be tested between temperature and depth in GAM models.

Population Density Estimation

The Working Group discussed possible issues for using supplemental survey data to calibrate NMFS survey data. These issues include uncertainty of area swept, diel migration of fish, tow duration, and availability of tow-specific sensor data. These concerns merit further research. The analysis would benefit from controlled side-by-side tows involving both vessels. Estimates were only applied in the southern region where the surveys overlapped.

Three methods were presented to calculate an expansion factor of silver hake density between NMFS and supplemental surveys, and the viability of each method was discussed. Small sample sizes were a concern for all of these models. The first method estimated a median density by year and strata in order to obtain a ratio of relative fishing power, but was inefficient in utilizing the available data. The second method was to use a conventional ratio estimator. The bootstrap estimates of precision for this method show substantial bias due to small sample size. A third regression method using density by tow was performed in order to use the survey data most efficiently and account for depth and other effects. The regression method had the narrowest confidence intervals, and was agreed to be the best model using the supplemental survey data.

Finally, a catch-survey ratio method was applied to both stock areas. This method gives a reasonable minimum biomass estimate since the catch in the years of greatest fishing effort cannot exceed the total biomass. Concerns were expressed that the bootstrap results from this method do not reflect all of the uncertainty since a constant catchability is assumed, and a minimum estimate of biomass is not comparable between years. Due to the difficulty in

comparing this assessment to previous years and the potential to ignore missing older fish, it was recommended that future assessments be based on model-based assessments.

Research Recommendations:

- A study be conducted to verify silver hake species identification with port agents, and to take additional age samples of larger commercial silver hake.
- The presence of silver hake in stratum 99 of NMFS surveys as well as in special deepwater surveys needs to be examined in order to determine if the NMFS survey is missing silver hake in deeper waters, and if additional tows in existing NMFS deep water stations would be beneficial. All available surveys that cover depths in excess of NMFS surveys should be examined for the distribution of silver hake.
- Acoustics data could be examined to augment silver hake distributions.
- Review effects of gear changes in NMFS survey on catchability of silver hake by size.
- Devise a method to cast the current survey based reference points into a form that is compatible with abundance indices derived from the new vessel.
- A study needs to be conducted to determine the extent of movement along the coast, especially around Georges Bank.
- The next assessment be based on an age-structure model, and reference points be derived from model results.

Sources of Uncertainty:

- There is uncertainty in the aging precision of silver hake from NMFS surveys due to changes in sectioning methods and age readers.
- Offshore hake could be incorrectly identified as silver hake, especially in commercial data.
- Gear changes in NMFS survey could affect catchability of silver hake over time.
- There is uncertainty as to whether silver hake is appropriately divided into two stocks.
- The NMFS surveys may have reduced catchability and coverage in deep water, and may not capture a good representation of the larger silver hake.

APPENDIX A4: Supporting information. Information in this appendix was presented and discussed during the SARC review meeting but not presented in the original assessment document. In most cases, the information was not presented in the original document because it was requested by the reviewers or prepared during discussions. This information was not discussed to the Working Group that prepared the assessment.

Figure 1 (APPENDIX A4) . Silver hake discards and landings (hail weights) for all trips (all gear and primary species groups) with observers during 2001-2004.

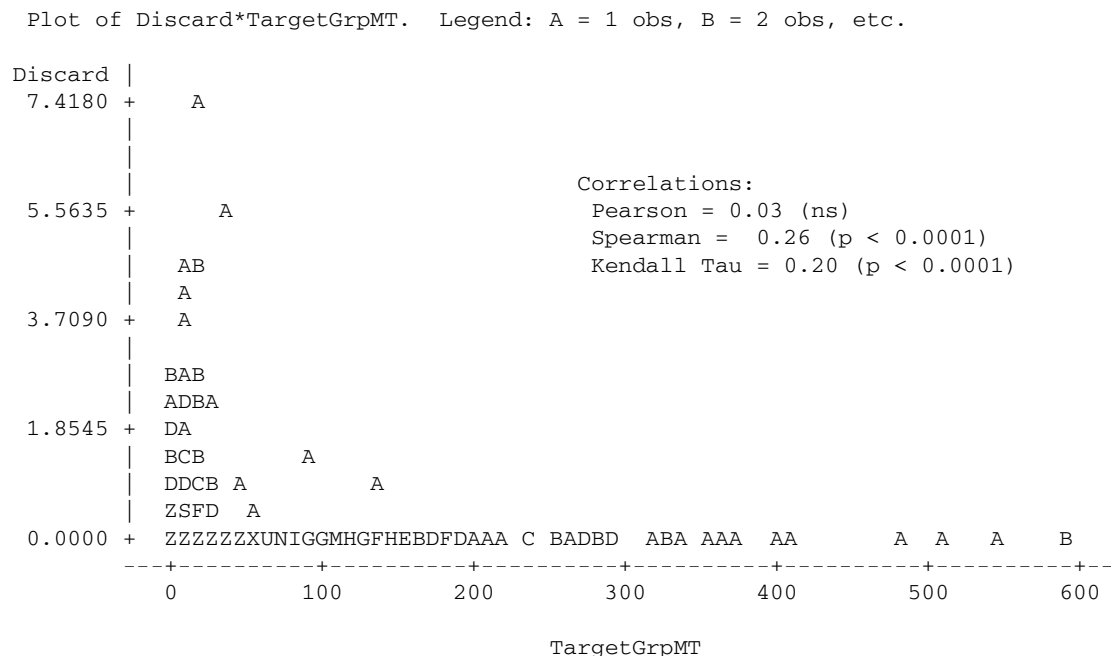
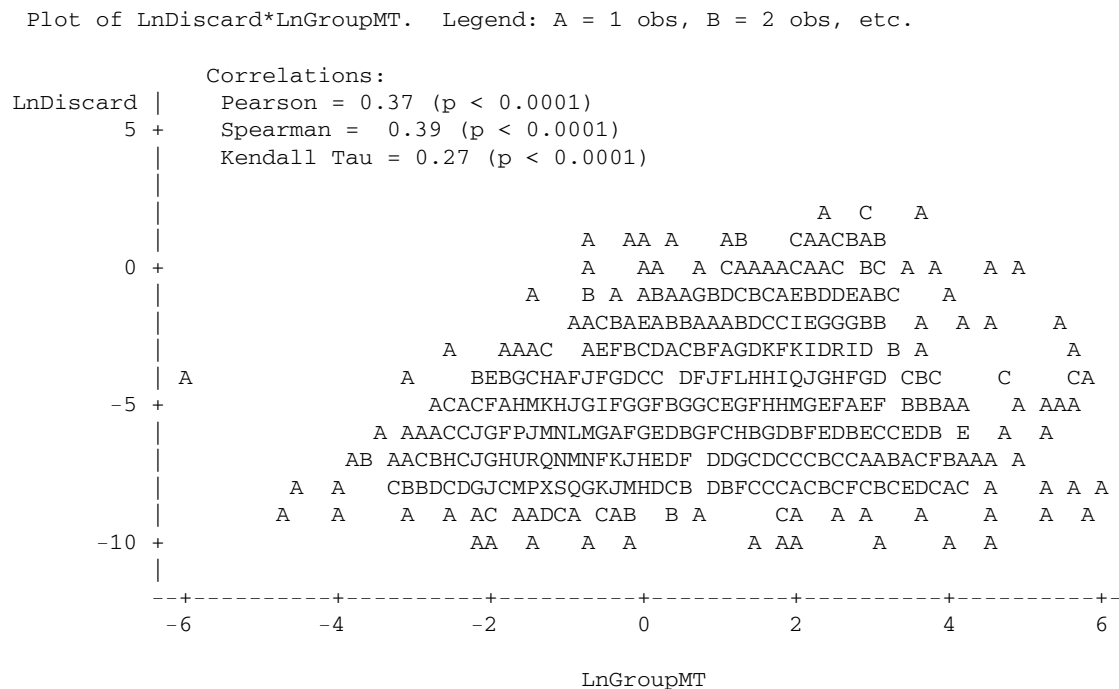


Figure 2 (APPENDIX A4). Same as previous figure except that trips with zero discards are omitted and both axes are log scale.



Plot 1: Linear Scale

Plot of Discard*TargetGrpMT. Legend: A = 1 obs, B = 2 obs, etc.

Discard	TargetGrpMT	Labels
7.3881	~10	A
6.3326	-	-
5.2772	~40	A
4.2217	~10	A
4.2217	~20	A B
3.1663	~30	A
2.1109	~10	ABA
2.1109	~15	ABABBA
1.0554	~20	BB BAA
1.0554	~40	CBBA A A A
1.0554	~80	A
1.0554	~100	A
1.0554	~120	AA
1.0554	~180	A
1.0554	~200	A A
1.0554	~270	AAA
1.0554	~290	B
0.0000	~5	ZZZZZUKECFB
0.0000	~70	BB A
0.0000	~100	A
0.0000	~120	AA
0.0000	~180	A
0.0000	~200	A A
0.0000	~270	AAA
0.0000	~290	B

Plot 2: Logarithmic Scale

Plot of Discard*TargetGrpMT. Legend: A = 1 obs, B = 2 obs, etc.
(NOTE: 50 obs hidden. 1429 obs out of range.)

Discard	TargetGrpMT	Labels
10000	~10	-
1000	-	-
100	-	-
10	~100	A
1	~0.1	A
1	~1	AA BB BGBAKCIFEAB A
0.1	~0.01	ACABFCHFIIHNOZPZKE A
0.01	~0.001	DALJOIPSPLHNWUZZRZKEBB A AC
0.001	~0.0001	BAADLMQZZUZKNRJLFRQLQNMGLFAA
0.0001	~0.00001	B B CDCEKHNMHBCFCBCDGAAFB A
0.0001	~0.1	AA A
0.0001	~10	AAA A A

TargetGrpID=Squid/ButterFish

Plot of Discard*TargetGrpMT. Legend: A = 1 obs, B = 2 obs, etc.

Discard

7.3881 + A

6.3326 +

5.2772 + A

4.2217 + A B

3.1663 + A

2.1109 + BAABA

1.0554 + AB BAA A

0.0000 + AAA A A A CCAECD ZUQHGGJDDDB B A A A A AA B

TargetGrpMT



Figure 5 (APPENDIX A4). *Top*: Silver hake discards and landings (hail weights) for the Hakes and Ocean Pout primary species group and Trawls gear group based on trips with observers during 2001-2004. *Bottom*: Same as top but records with zero discard are omitted and both axes are log scale.

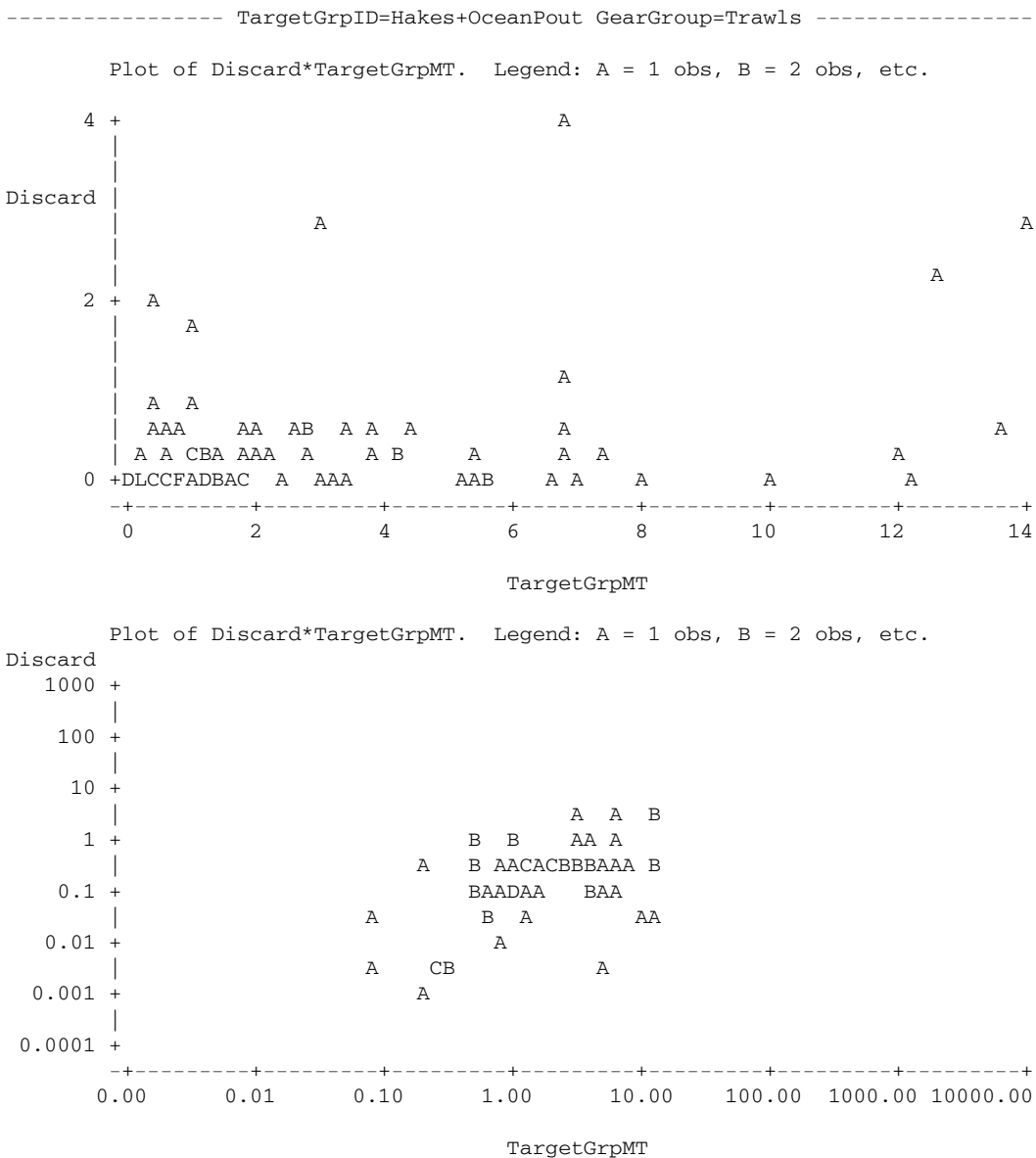


Figure 6 (APPENDIX A4). *Top*: Silver hake discards and landings (hail weights) for the Squid and Butterfish primary species group and Trawl gear group based on trips with observers during 2001-2004. *Bottom*: Same as top but records with zero discard are omitted and both axes are log scale.

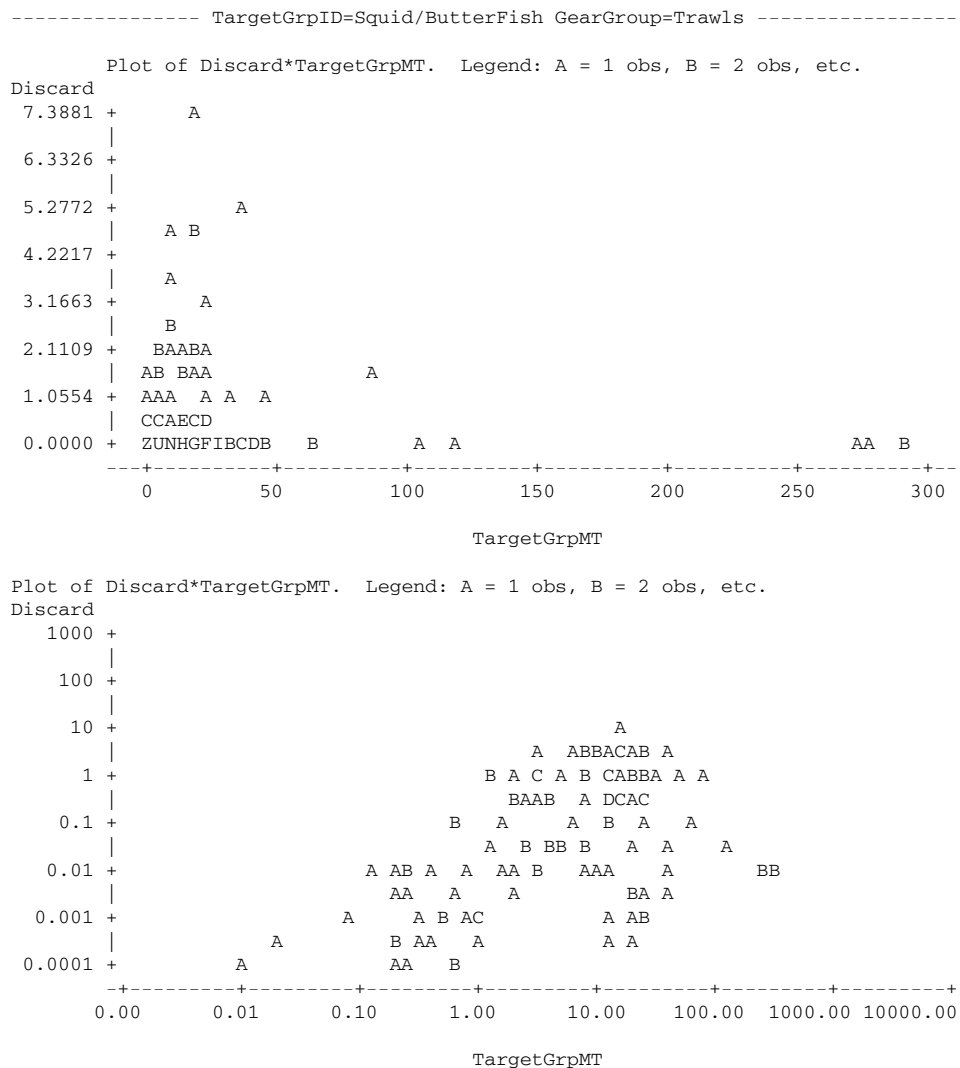
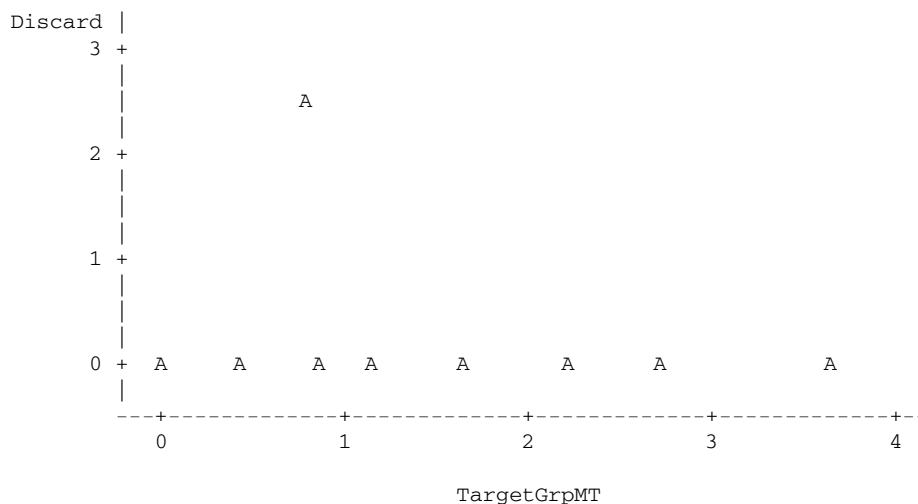


Figure 7 (APPENDIX A4). *Top*: Silver hake discards and landings (hail weights) for the Hakes and Ocean Pout primary species group and Other/unknown gear group based on trips with observers during 2001-2004. *Bottom*: Same as top but records with zero discard are omitted and both axes are log scale.

----- TargetGrpID=Hakes+OceanPout GearGroup=Other/unknown gear -----

Plot of Discard*TargetGrpMT. Legend: A = 1 obs, B = 2 obs, etc.



Plot of Discard*TargetGrpMT. Legend: A = 1 obs, B = 2 obs, etc.

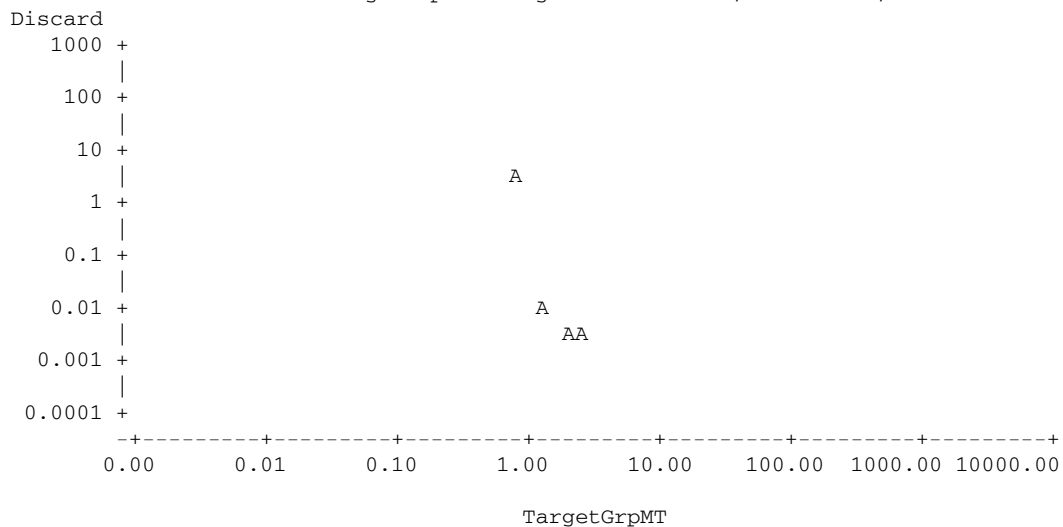
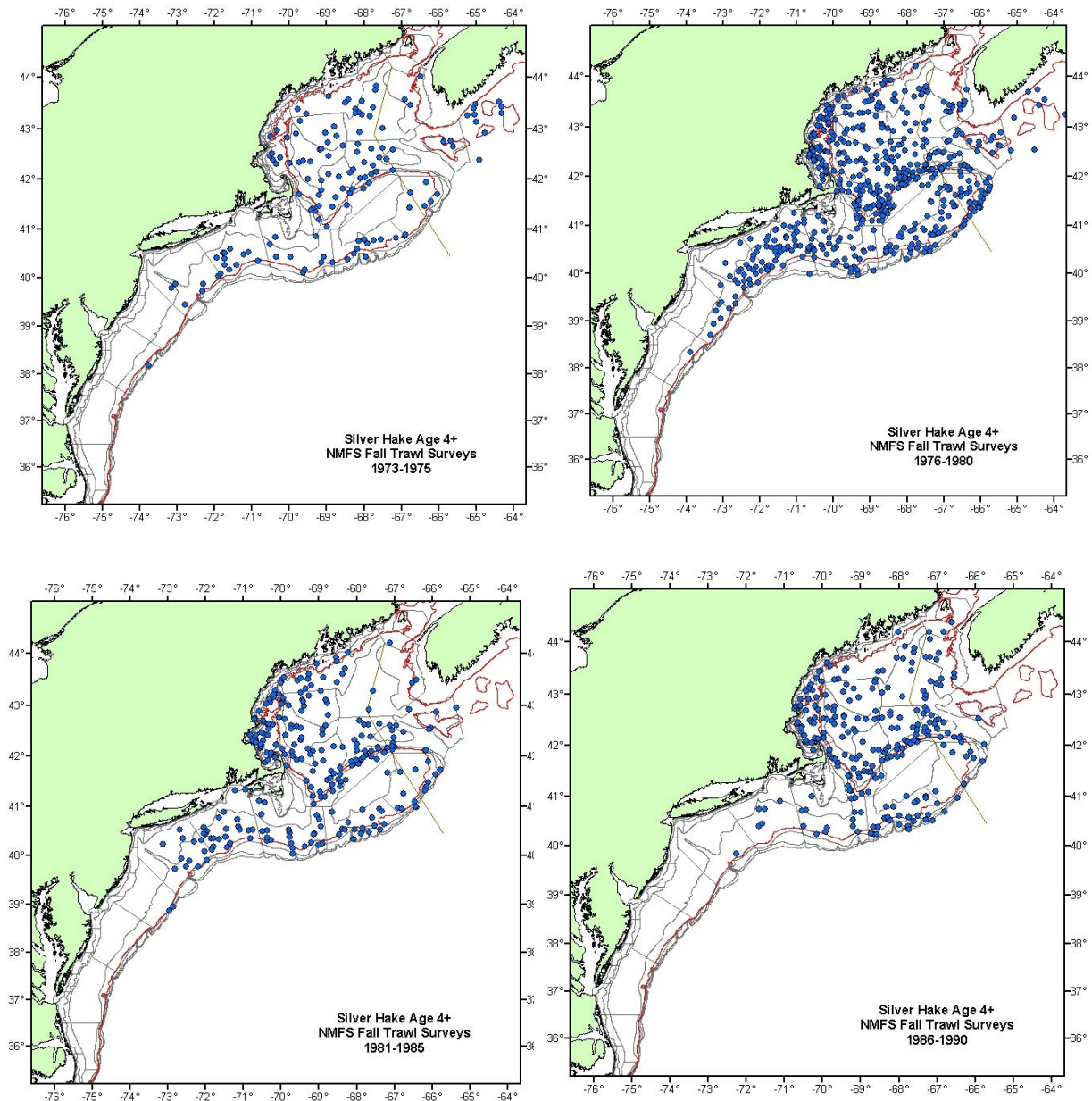
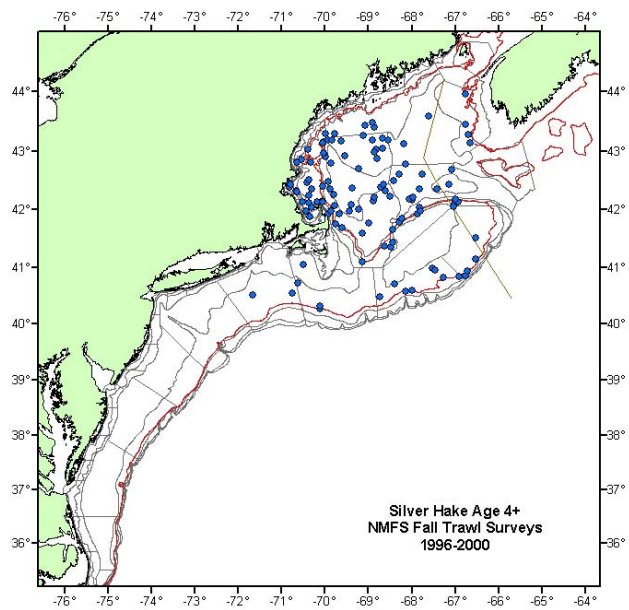
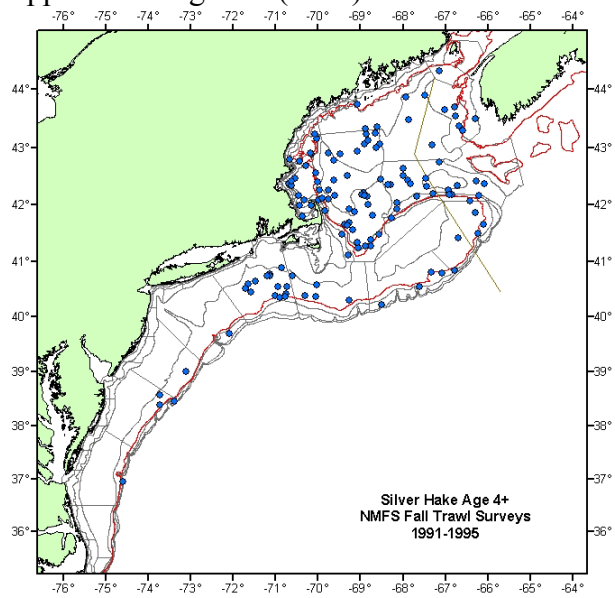
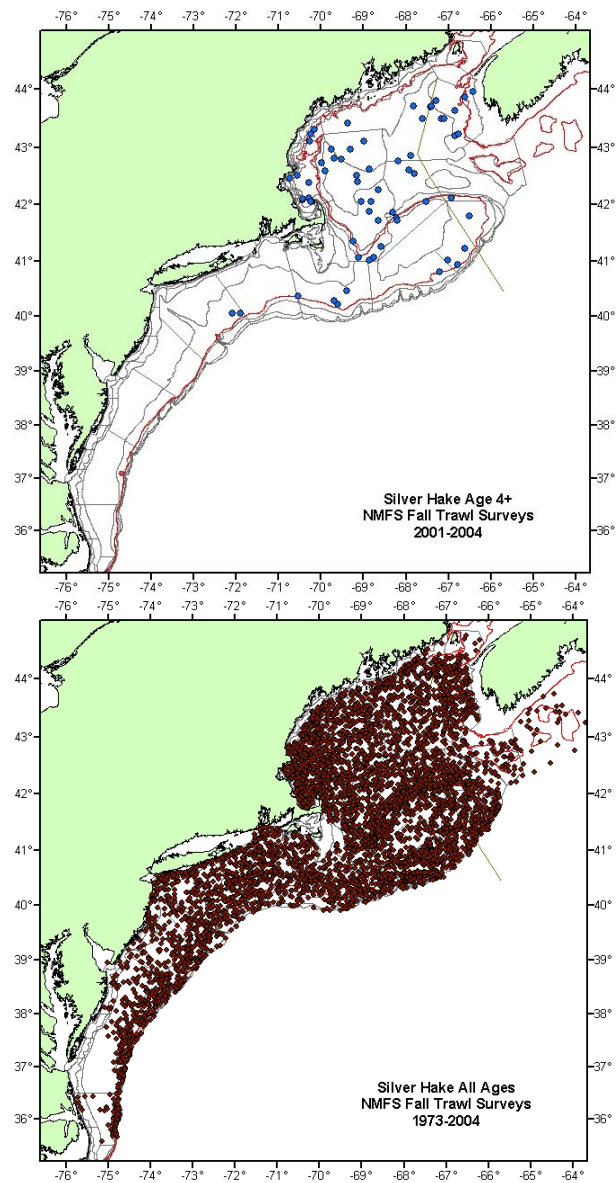


Figure 8 (APPENDIX A4). Location of tows with silver hake ages 4+ for NEFSC fall bottom trawl surveys during 1979-2004. The plots show the successive reduction in abundance of silver hake ages 4+ in the southern area over time. The last panel shows the location of all tows with silver hake of all ages during all years and, in comparison to other panels, shows the tendency for relatively young (ages 1-3) silver hake to use southern and nearshore habitats.



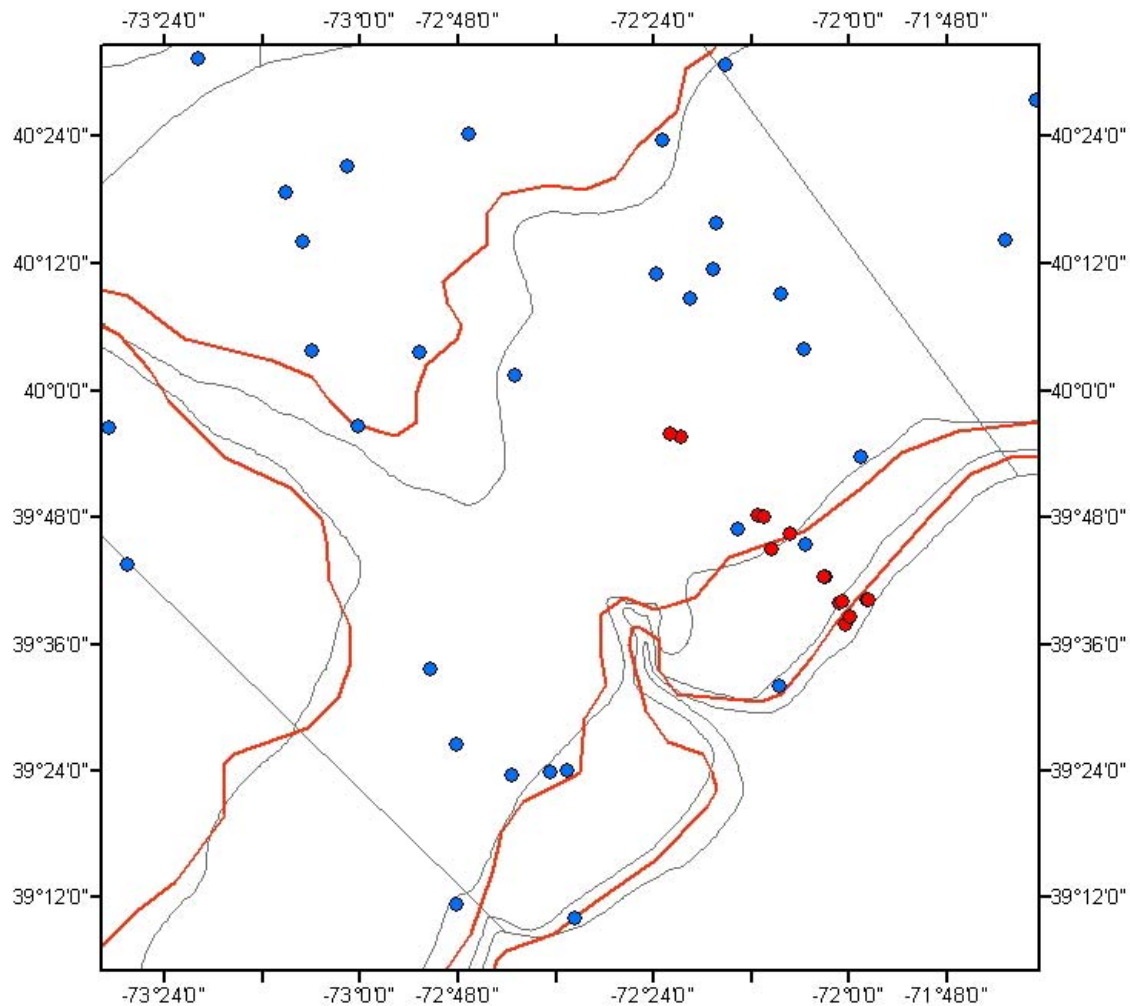
Appendix 5 Figure 8 (cont.)





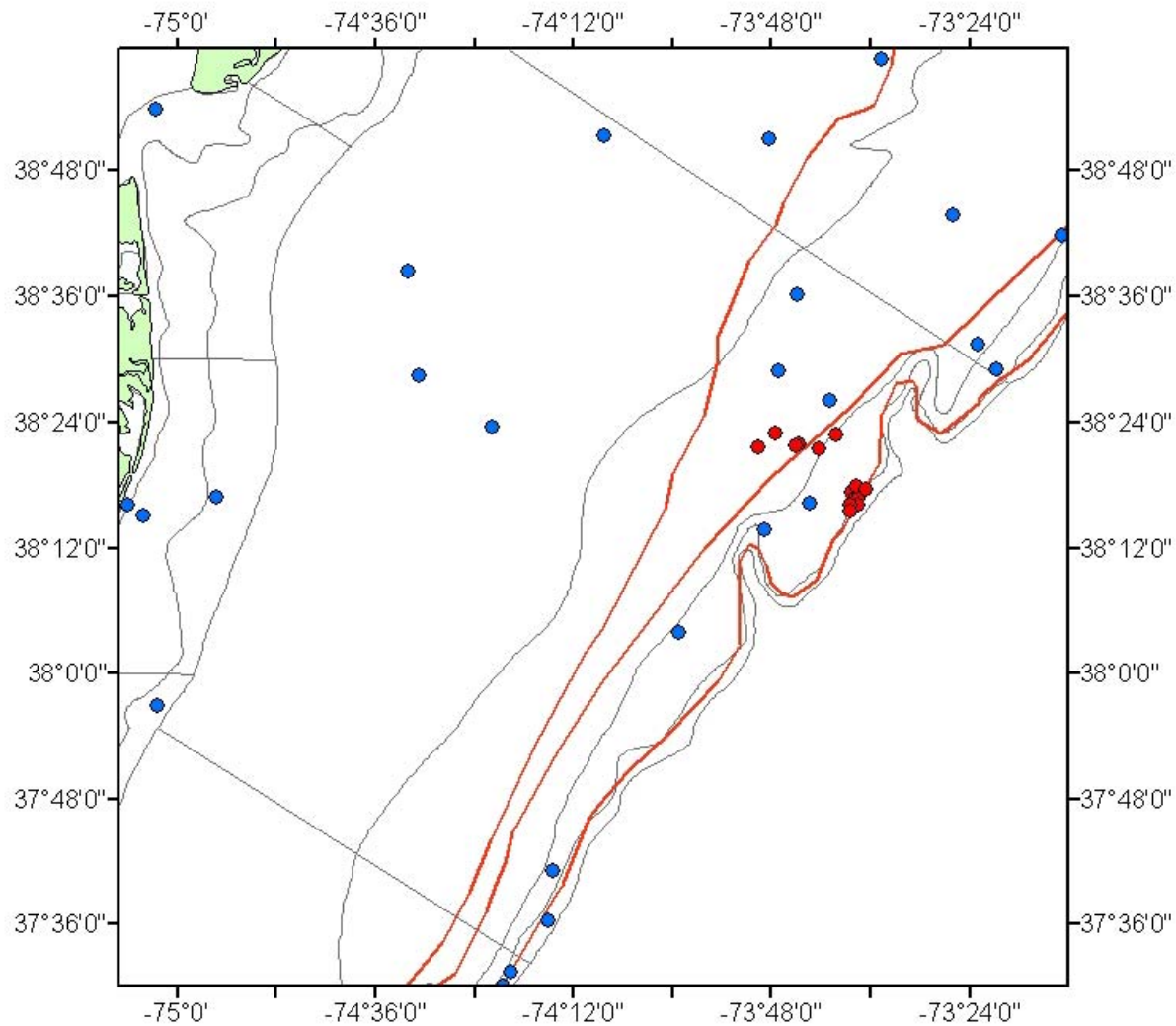
Appendix 5 Figure 8 (cont.)

Figure 9 (APPENDIX A4). Location of random NEFSC spring bottom trawl survey tows (blue dots) and fixed Supplemental (Transect) bottom trawl survey tows (red dots) in the Hudson Canyon area during 2004-2005 that were used to estimate relative fishing power. Red lines show the 50, 100 and 200 m depth contours. Dark lines show NEFSC bottom trawl survey strata.



**Silver Hake in Hudson Canyon
NMFS Spring Trawl Surveys
and Supplemental Survey**

Figure 10 (APPENDIX A4). Location of random NEFSC spring bottom trawl survey tows (blue dots) and fixed Supplemental (Transect) bottom trawl survey tows (red dots) in the Baltimore Canyon area during 2004-2005 that were used to estimate relative fishing power. Red lines show the 50, 100 and 200 m depth contours. Dark lines show NEFSC bottom trawl survey strata.



**Silver Hake in Baltimore Canyon
NMFS Spring Trawl Surveys
and Supplemental Survey**

Figure 11 (APPENDIX A4). Text slides with information about Supplemental survey transects and stations that were requested by reviewers.

Map points

- Stations at 40, 50, 60, 80, 100 and 150 fathoms
 - Fixed locations only (same each year)
- Transects not on edge of canyons where fish may “pile up”
- Only two transects
 - Don’t know how representative

Randomizer’s

- Multispecies survey (like NEFSC)
 - None given higher importance
- Seasonal variation in migration patterns
- Tides
- Migratory patterns not pronounced in March
 - Winter hiatus?
- Away from canyons where fish can mix and don’t pile up

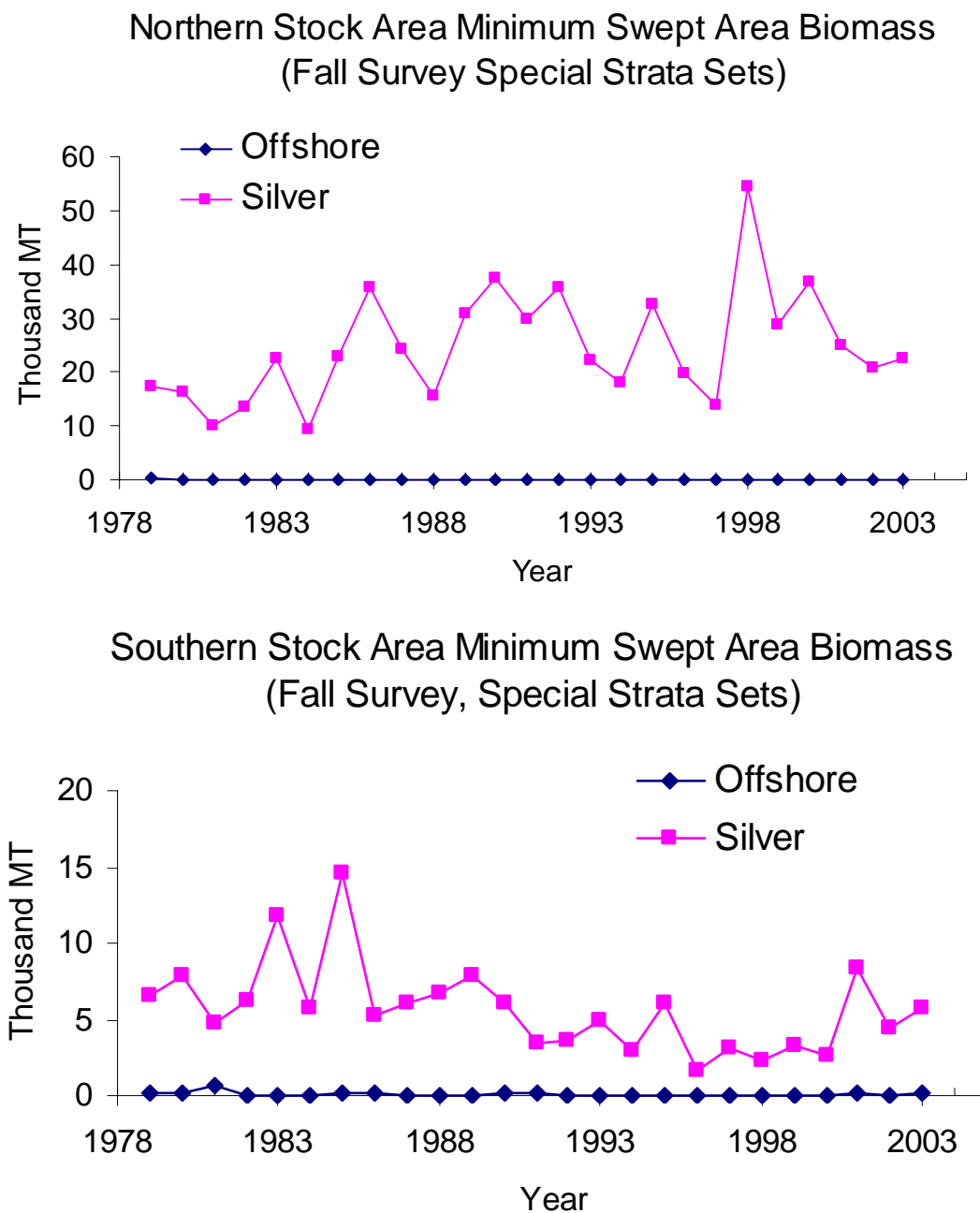
Transects

- Survey meant to answer questions about the timing of fish migrations (time at which fish cross the transect)
 - Away from canyons where fish might pile up
- Same transects for multiple target species at various times of year
- On steep grounds to minimize distance over transect
- Maximize trawable ground
 - Minimize gear damage
 - Same as NEFSC
- Proximity to other transects
 - Reduce steaming time
- Away from the “bend” north of Hudson canyon
- Away from really poor fishing grounds (i.e. not trawable)
- Selected by a panel of different backgrounds

Bottom line

- Not a side-by-side gear experiment
- Only two transects
- Transects on towable ground where catch can be expected
- Not designed (on purpose or inadvertently) to maximize catch of silver hake

Figure 12 (APPENDIX A4). Minimum swept-area biomass (mt) for silver hake and offshore hake in the northern and southern stock areas based on NEFSC fall survey data and the special survey strata set.



B. ATLANTIC MACKEREL STOCK ASSESSEMENT

TERMS OF REFERENCE

1. Characterize the commercial and recreational catch including landings and discards.
2. Estimate fishing mortality, spawning stock biomass, and total stock biomass for the current year and characterize the uncertainty of those estimates. If possible, also include estimates for earlier years.
3. Evaluate and either update or re-estimate biological reference points, as appropriate.
4. As needed by management, estimate a single-year or multi-year TAC and/or TAL by calendar year or fishing year, based on stock biomass and target mortality rate.
5. If possible,
 - a. provide short term projections (2-3 years) of biomass and fishing mortality rate, and characterize their uncertainty, under various TAC/F strategies and
 - b. evaluate current and projected stock status against existing rebuilding or recovery schedules, as appropriate.
6. Review, evaluate and report on the status of the SARC/Working Group Research Recommendations offered in previous SARC-reviewed assessments

EXECUTIVE SUMMARY

(TOR 1) Atlantic mackerel were heavily exploited by distant water fleets during the 1970's. Total landings in NAFO subareas 2-6 averaged 350,000 mt during 1970-1976, but this level was not sustainable (Figure B1). Annual landings decreased to less than 50,000 mt during 1978-1984. Landings in Canada remained relatively constant at an average of 24,000 mt during 1968-2000. Landings in the US EEZ increased during 1985-1991 to an average of 76,000m t, with the advent of a JV fishery in the Mid-Atlantic region. More recently landings by both the USA and Canada have increased as world demand has improved. Commercial landings in the U.S. increased from a low of 5,646m t in 2000 to 53,724 mt in 2004, while landings in Canada increased form 13,383 mt in 2000 to 51,444 mt in 2004. Recreational landings of mackerel in the USA averaged 1,344 mt during 1990-2000, but decreased from 1,538m t in 2001 to only 467 mt in 2004.

The northwest Atlantic mackerel stock is not overfished and overfishing is not occurring relative to the new reference points from this assessment. (TOR 2) Fishing mortality has remained low for the last decade, but increased slightly from 0.02 in 2002 to 0.05 in 2004. The confidence interval (± 2 SD) for F in 2004 ranged from 0.035 to 0.063, but retrospective analysis shows that

F has sometimes been underestimated in recent years. The overfishing reference point, F_{msy} , was re-estimated at $F_{msy}=0.16$ (previously $F_{msy}=0.45$).

(TOR 2) Spawning stock biomass increased steadily over the last several decades from a low of 663,000 t in 1976 to 2.3 million mt in 2004. The confidence interval on SSB (± 2 SD) ranged from 1.49 to 3.14 million mt in 2004; however, retrospective analysis showed that SSB has sometimes been overestimated in recent years. The biomass reference point was re-estimated in this assessment at $SSB_{msy}=644,000$ mt (previously $SSB_{msy}=890,000$ mt).

(TOR 3) Fishing mortality based biological reference points (BRP's) were re-estimated during SARC 42. Fishing mortality reference points are $F_{0.1} = 0.25$ and $F_{40\%} = 0.24$. Reference points from model estimated B-H parameters are $MSY = 89,000$ mt, $SSB_{msy} = 644,000$ mt, and $F_{msy} = 0.16$. Surplus production in the mackerel stock was available sporadically during 1962-2004. Periods of positive SP occurred before the ICNAF fishery in the late 1960s, during the early 1980s, and more recently in the late 1990s through 2003. The average SP available during 1962-2003 was 148,000 mt; this can serve as a proxy upper bound on MSY for the current assessment. Stock-recruitment BRP's were estimated prior to SARC 30 using a bootstrap method as $F_{msy}=0.45$, $F_{target}=0.25$, $MSY=326,000$ mt, and $SSB_{msy}=887,000$ mt (NEFMC 1998); these should be replaced with the more current values.

(TOR 4, 5) Deterministic projections for 2006-2008 were conducted by inputting an estimated catch of 95,000 mt in 2005 and a target fishing mortality of 0.12 (MAFMC 1998, $F_{target}=0.75 \times F_{msy}$) in 2006-2008. If 95,000 mt are landed in 2005, SSB in 2006 will increase to 2.6 million mt. If the $F_{target} F=0.12$ is attained in 2006-2008, SSB will decline to 2.3 million mt in 2007 and to 2.0 million mt in 2008. Landings during 2006-2008 would be 273,000 mt, 239,000 mt, and 212,000 mt, respectively. These landings are the result of an unusually large year-class (1999) present in 2005, and will not be sustainable in the long term. It is expected that these projected landings will decline to MSY (89,000 mt) in the future when a more average recruitment condition exists in the stock.

1.0 INTRODUCTION

Atlantic mackerel (*Scomber scombrus*) are distributed from North Carolina to the Gulf of St. Lawrence, and on occasion as far north as Labrador (Bigelow and Schroeder 2002). Mackerel are a fast moving, schooling species that undergo extensive seasonal migrations. The northern and southern components generally over-winter on the continental shelf off the Mid-Atlantic bight and begin their spring migration in April. The southern component spawns along the Southern New England corridor and disperses throughout the Gulf of Maine-Georges Bank region during summer (Sette 1950; Morse et al. 1987; O'Brien et al. 1993). It is believed that the northern component crosses Georges Bank during April-May reaches the Scotian shelf in late May or early June and moves into the Gulf of St. Lawrence during late June and early July to spawn in the Magdalen shallows region (Sette 1950; Gregoire et al. 2003; DFO 2004; Gregoire 2005). Post spawning fish disperse into the Gulf as far east as Newfoundland. This schooling species often attains ages greater than 10; ages up to 14 are not uncommon. Mackerel begin to mature at age 2, and are generally fully mature at age 3 (Bigelow and Schroeder 2002; Gregoire et al. 2003). They exhibit a planktivorous diet, feeding mainly on zooplankton, chaetognaths,

euphasids; and larval fish (Bigelow and Schroeder 2002). Mackerel are preyed upon by a large number of medium-sized predatory fishes such as cod, white hake, and spiny dogfish; marine mammals such as pilot whales, white-sided dolphins, and common dolphins; seabirds such as greater shearwaters and northern gannets; and large pelagic fish such as swordfish and blue shark, throughout their range.

The Mid Atlantic Fishery Management Council manages mackerel as part of the Atlantic mackerel, Squid, and Butterfish (MSB) Fishery Management Plan. The current overfishing definition is based on an MSY of 326,000 mt, a Bmsy of 890,000 mt, and a limit fishing rate of $F_{msy} = 0.45$ (MAFMC 1998; NEFMC 1998). Overfishing for this species is defined as occurring when F_{msy} is exceeded, and the overfishing limit is $F_{msy} = 0.45$ when the SSB is greater than 890,000 mt. An MSY of 326,000 mt represents the current estimate of long-term potential catch for the stock and was revised in Amendment 8 of the FMP. The F target is defined as the tenth percentile of F_{msy} and is set at $F=0.25$. If SSB is less than 890,000, F target decreases linearly from 0.25 at 890,000 mt to zero at 450,000 mt. The biomass target for this stock is defined as Bmsy and the minimum biomass threshold is defined as $\frac{1}{2}$ Bmsy. There have been a series of amendments to the MSB Fishery Management Plan; the most recent amendment (Amendment 9) does not propose any changes for the mackerel OFD.

The most recent assessment for this stock was completed in 1999 (SARC 30) (NEFSC 2000). Although no quantitative assessment was accepted, conclusions were that the stock was at a high level of biomass, F was low, and that catches were well below the MSY of 326,000 mt.

2.0 THE FISHERY

Commercial Landings

Commercial mackerel landings by the United States averaged 2,368 mt from 1960-1983, peaked at 31,261 mt in 1990, and declined to 4,666 mt in 1993 (Table B1; Figure B1). USA landings increased to 16,137 mt in 1996, declined to 5,646 mt in 2000 and steadily increased to 53,724 mt in 2004. Recreational landings in the USA have generally declined during 1979-2004. Landings averaged 2,945 mt during 1979-1988 and declined to a low of 344 mt in 1992 (Table B1; Figure B1). Landings in the US sport fishery peaked at 1,735 mt in 1997, declining slightly thereafter, but remaining relatively steady until declining to 724 mt in 2003 and 467 mt in 2004. Landings by Canada averaged 6,891 mt during 1960-1967, and 23,882 during 1968-2000 (Table B1; Figure B1). Canadian landings increased steadily from 23,868 mt in 2001 to 51,444 mt in 2004. For details of Canadian landings see Gregoire et al. (2003), DFO (2004), and Gregoire (2005) available online at www.dfo-mpo.gc.ca/csas. Landings by foreign countries, primarily during the ICNAF era, averaged 143,532 mt during 1961-1977, and 18,315 mt during 1978-1991 (Table B1; Figure B1). Foreign countries were excluded from fishing in the US EEZ after 1991.

Sampling Intensity

Commercial length frequencies used to characterize USA landings were obtained from port samples obtained in the Northeast Region. The mackerel fishery is strongly seasonal, with most of the landings occurring during the first 5 months of the calendar year and any remaining landings during November and December. Because of stable growth patterns, length samples

were aggregated over the first and second half of each year. Most of the landings occurred during the first half of the year in all years from 1998-2004, but in some landings occurred in the second half of the year during 2001-2004 (Table B2). Sample size for commercial length compositions ranged from 907 in 2000 to 4,297 in 1999 for the first half of each year (Table B2). Sample size for length data for the commercial fishery in the second half of 2001-2004 ranged from 116 in 2001 to 322 in 2003. Landings at age for the second half of 2001-2004 were estimated with length data from the 4th quarters of each year (Table B2). A length-weight relationship was used to estimate sample weight and expansion factors for commercial samples from 1998-2004. Length-weight parameters used in the last assessment ($a=0.0059$, $b=3.154$) were used for the estimation of commercial catch at length.

Recreational length samples obtained from the MRFSS data base were used to characterize the landings of this species by sport fisherman. Sample numbers and lengths were judged to be adequate enough to estimate recreational catch at length. Recreational length samples were available for each year during 1998-2004 and ranged from 483-1,347 fish measured (Table B2). The same length-weight equation was used to estimate sample parameters and expansion factors for the recreational landings data.

Age length data used for estimating commercial and recreational catch at age were obtained from commercial port samples, sea sampling, and NEFSC Spring and Winter bottom trawl surveys. Combined age-length keys from these sources were used to age commercial and recreational landings from the first half of 1998-2004 (Table B2). Sample size for the first part of the year during 1998-2004 ranged from 719-1901 (Table B2). Generally only fall survey ages in small numbers were available to age the second half of each year during 2001-2004, samples sizes ranged from 71-121. Catch-at-age for Canada was developed using similar procedures, although many more length samples were available. For details of Canadian commercial length and age sampling see Gregoire et al. (2003), DFO (2004), and Gregoire (2005) available online at www.dfo-mpo.gc.ca/csas.

Catch-at-Age

USA commercial and recreational catch at age for 1962-1997 were taken from the previous assessment (NEFSC 2000). Catch at age for the USA during 1998-2004 were estimated from the length and age composition and landings data previously cited (Table B3). Canadian catch at age data for 1998-2004 were obtained from DFO Canada (Gregoire et al. 2003) and are included in Table (B3). Canadian catch-at-age data for 1990-1993 were updated based on a revision in Canadian landings for 1990-1993. For details of Canadian catch-at-age see Gregoire et al. (2003), DFO (2004), and Gregoire (2005) available online at www.dfo-mpo.gc.ca/csas.

Commercial Mean Weights

Commercial mean weights used in the current assessment were obtained from the previous assessment for 1962-1997 and were estimated for 1998-2004. The length weight relationship used to estimate sample weights ($a=0.0059$, $b=3.154$) was used to calculate the mean weights at age for the USA commercial fishery for 1998-2004. Mean weights for the commercial fishery

during 1998-2004 were calculated as weighted means of the USA and Canadian fishery catch-at-age and mean weights-at-age (Table B4).

3.0 RESEARCH SURVEY ABUNDANCE INDICES FOR TREND

Research survey abundance indices are available from winter and spring NEFSC bottom trawl surveys for assessing the status of the mackerel resource. Survey indices are available from NMFS surveys for the winter 1992-2005 and spring 1968-2005. The autumn survey series from 1963-2004 was investigated for use as a tuning index, but very few mackerel are taken in this survey and an unknown proportion, perhaps large, is distributed in Canadian waters, and is unavailable to the USA survey.

Standard and ln transformed spring survey indices were updated for 1998-2005. Standard indices in weight and number per tow continued to show improving trends for the stock during 1989-2005 (Table B5; Figure B2). The biomass index generally increased from 1989-1996, declined slightly in 1997-1998, and increased from 1999-2004. Mean number per tow indices followed nearly the same trends, increasing over the early 1990s, decreasing in 1997-1998, and increasing again from 1999-2004. The index reached 116 in 2001, the highest value in the 43 year series (Table B5; Figure B2).

Spring indices for 1998-2004 were recomputed to produce aggregated ln retransformed catch per tow indices. The standard number per tow index increased by an order of magnitude from the 1980s to the 1990s and increased further from 1998-2004. The index was high and relatively stable throughout the 1990s, except for 1997 and increased in 2000 and 2001 (Table B5; Figure B4). The highest value in the series was obtained in 2001 (59.106). Number per tow indices at age (ln retransformed) were updated for 1998-2005. Indices at age were generally higher, with a few exceptions, for ages 1-6 during 1997-2004 than for all other years in the 1968-2005 time-series (Table B6).

The winter bottom trawl survey began in 1992 and was included as an index for this stock in the previous assessment. The standard biomass and abundance indices for mackerel are generally high, but variable (Table B7). The biomass index ranged from 0.25-32.05 kg/tow during 1992-2005 (Table B7; Figure B4). Number per tow ranged from 1.16 to 245.58 during this same period. Some of the variation in survey indices may be attributed to the more inconsistent coverage of survey strata during the winter survey. Number per tow at age indices (ln retransformed) were produced for the winter survey, including ages 1-10+ (Table B8). Indices in this survey have also increased in recent years (Table B8).

Growth

Trends in average weight from the spring survey were examined to see if there were any changes during 1968-2005. With the exception of the period after the ICNAF fishery in the 1970s, average weights have fluctuated between 100-200 grams, but there appears to be a slight overall decline from 1985 onward (Figure B6). Average weight-at-age from the USA and Canadian fishery were also examined for trends (Figure B7). The same increase in weight occurred

following the ICNAF era, but mean weights have been relatively constant since then and very similar to weights in the 1960s through the mid-1970s (Figure B7).

Predation Mortality

Evidence suggests that natural mortality rates for this species may be more variable than the current constant value ($M=0.2$) used in assessments. Overholtz et al. (2000) studied consumption of pelagic fishes and squids in the Northeast shelf ecosystem and found that the pelagic fish community in the region is heavily consumed by predatory fishes in the region. This study suggested that mackerel were important in the diets of predatory fish in the region during 1973-1997. Consumption by predatory fish as a group was certainly important during this time (Figure B8). Spiny dogfish are an important consumer of mackerel, removing significant quantities of this prey species during 1979-1997 (Figure B9).

Mackerel Distribution

The positions of mackerel survey catches during 2002-2005 from the NEFSC spring survey were plotted to observe if any changes in distribution had taken place over that time period. Mackerel were widely distributed over the Mid-Atlantic-Georges Bank region during 2002 (Figure B10). During 2003, mackerel were further to the south and distributed about midway along the Mid-Atlantic continental shelf (Figure B11). In 2004, the mackerel distribution was further to the south and further offshore than in 2003 (Figure B12). Mackerel survey catches were much further to the south and more offshore in 2005 than during the three previous years (Figure B13).

4.0 VPA CALIBRATION AND DIAGNOSTICS

Catch-at-age and mean weight data for 1962-2004 and bottom trawl survey data for winter 1992-2004 and spring 1968-2004 (ages 1-10+), were used in a VPA calibration to update the previous assessment (NEFSC 2000). Results from this run suggest that current spawning stock biomass is rebuilding, but much below levels observed in the early 1970s (Figure 1 App1). Fishing mortality increased steadily from 1980 through 2002, reaching very high values of 0.7 in 1999 and over 1.0 in 2002 (Figure 2 App1). Trends in the observed vs./ predicted series for the spring survey show patterning with a block of negative residuals prior to 1984 and positive residuals thereafter (Figure 3 App1). Observed-predicted trends from the winter survey are mixed, but the fit is reasonable (Figure 4 App1). Since there was a prominent retrospective pattern in the previous assessment, a new analysis was completed. There is still a prominent retrospective pattern for spawning stock biomass in the current VPA with successive years from 2002-2004 showing major declines in SSB when compared to the previous year (Figure 5 App1). Fishing mortality also had a pattern indicating that F was underestimated during 2002-2004 (Figure 6 App1).

Since the retransformed winter trawl series is relatively flat (Figure B5) and residual patterns for the spring survey from the previous run were poor, the next VPA run utilized only the spring survey time-series. The spring series is the longest time-series available and has long been considered the best available index for monitoring trends in this stock. Scaling was a problem

with this model run, spawning stock biomass increased to very high values, exceeding 40 million mt during 2000-2004 (Figure 7 App1). The pattern in fishing mortality was much different than in the first run, with higher mortality rates in the 1970s and much lower F's from the 1980s onward (Figure 8 App1). Model fit improved greatly in this model formulation (Figure 9 App1). However, because of the many problems encountered in the VPA formulations, another more flexible modeling approach (ASAP), that can be used to address issues such as fishery selectivity, biomass scaling, and recruitment estimation, was utilized.

5.0 ASAP FORWARD PROJECTION DESCRIPTION

ASAP is an age structured forward projection model with flexibility to address fishery selectivity, stock-recruitment, and constraints on virgin biomass, steepness, scale and other factors. The analysis for Atlantic mackerel starts in 1962 and projects forward through 2004. Total biomass, spawning stock biomass, recruitment, fishing mortality, and surplus production are estimated in the model.

Growth

The same mean weight data from the VPA (1962-2004 ages 1-10+) were used in ASAP model runs.

Maturity

Maturity was assumed to be 0.2 at age 2 and 1.0 at age 3 and older for mackerel.

Natural Mortality

Natural mortality was assumed to be 0.2 as in previous assessments.

Partial Recruitment

Partial recruitment was assumed to be 0.2 at age 1, 0.6 at age 2 and 1.0 for age 3 and older. These data were based on the old VPA run (NEFSC 2000), the new VPA run and results in the recent USA fishery.

Recruitment

A Beverton-Holt stock-recruitment model was used to model recruitment with the alpha and beta parameters estimated internally in the model. In ASAP runs 1 and 2 the SR relationship was assumed to be fit without any error, while in run 3 and the base case run the relationship was fit with error ($\lambda=1$).

Surplus Production

Surplus production for the mackerel stock was estimated by using parameters from the B-H model fit. Stock recruitment parameters were estimated internally and used to calculate management parameters such as MSY and Fmsy. In addition output from the model was used to fit a Fox model (Fox 1975) and a Schaefer model (Schaefer 1954).

Landings

The total catch-at-age for the USA and Canada model were included in the ASAP formulations (Figure B3). For details of Canadian CAA see Gregoire et al. (2003), DFO (2004), and Gregoire (2005) available online at www.dfo-mpo.gc.ca/csas.

Research Surveys for Trend

The spring survey (1968-2004 ages 1-10+, and 1-7+) was used to tune the mackerel ASAP model.

6.0 ASAP INITIAL MODEL TRIALS AND RESULTS

A series of ASAP model runs were conducted to address various aspects of model scale and goodness of fit. The first model run repeated the last formulation used in the VPA, a run that utilized only the spring survey. Results from this trial showed an improvement in scale for spawning stock biomass when compared to the VPA (Figure 10 App1). The historic period during 1962-1977 was very similar in magnitude to the VPA, but the spawning stock increased steadily thereafter to over 6.5 million mt in 2003 (Figure 10 App1). The pattern in fishing mortality showed a large increase in the mid 1970s followed by very low rates thereafter (Figure 11 App1). However, a comparison of the observed vs. predicted survey series indicated that this model run produced estimated values that were functionally a smoothed series through the survey index values (Figure 12 App1). This occurred because the SR relationship was fit without error, resulting in a smooth trend in predicted survey values. Overall, this model run resulted in a large improvement in scaling when compared to the similar VPA run, but diagnostics (residuals) were very poor. To further address issues of scale and poor model fit, another ASAP model run was completed.

It is hypothesised that another important issue related to the spring time series is a change in catchability due to a conversion to polyvalent doors that occurred in 1985. After 1984, survey catches of mackerel on average increased dramatically when compared to values prior to the door change (Table B5; Figure B2). The GARM and trawl warp investigation in 2002 suggested that the current door configuration for the 36-Yankee trawl results in an overspread condition for the net (S. Murawski, pers. comm., 2002). This means that now the net is always open both high and wide. Evidence suggests that historically the 36-Yankee survey gear probably did not operate in this fashion because water hauls were common and the net probably functioned in a more compressed state (Pers. Comm. NEFSC Survey Group, *various years*). Results from door

comparison work that was completed on a variety of species, were not available for mackerel, because the design was oriented toward groundfish and few mackerel were available during the experiment (Byrne and Forrester 1991). Coefficients for Atlantic herring from this same gear study were not significant, but these experiments were not designed to estimate the effects of door changes on herring. Extensive work on herring in subsequent studies confirmed that the door change was an important factor in explaining survey catchability changes in the spring survey for this species (Overholtz et al. 2004). Therefore, the spring survey was split in 1985 to address the survey catchability issue for mackerel. The two separate series were used to tune the mackerel ASAP model in this model run.

Results from the ASAP model utilizing the split spring time-series showed an improvement in scale, but a continued smoothing of survey predicted values. Again, the smoothing resulted from the assumption of no error in the SR relationship. Spawning stock biomass increased steadily from the late 1970s to 4 million mt in 2003 (Figure 13 App1). Fishing mortality was high in the 1970s, increased in the late 1980s and early 1990s, and slightly increased in recent years (Figure 14 App1). Patterns in the observed vs. predicted spring survey series were apparent in the pre-1985 and post 1985 periods, as the ASAP model smoothed the predicted values (Figure 15; 16 App1).

As a further approach for addressing the problem of scale and patterns in residuals, some of the features of the ASAP model that are useful for addressing issues of scale directly were used. A stock-recruitment function (Beverton-Holt) was fit with a low emphasis coefficient ($\lambda = 1$) to attempt to improve these factors. Results suggest that biomass decreased substantially and the pattern in the residuals improved greatly. Spawning biomass in the 1970s peaked at over 1.5 million mt, declined, and then increased steadily from the late 1970s onward to a maximum of 2.7 million mt in 2003 (Figure 17 App1). Fishing mortality increased slightly in the 1970s over previous runs, but remained relatively low from 1980-2004 (Figure 18 App1). Patterns in the survey residuals improved greatly, with observed and predicted series tracking nicely for both the pre 1985 and post 1985 series, and with little patterning in both series (Figures 19; 20 App1). Results for the various likelihood components in the trial, base case, and sensitivity runs are presented in Table (B11).

7.0 BASE CASE MODEL

The base case model for mackerel used a CAA that was further aggregated to 7+. The recent lack of older aged fish in the spring survey (Table B6) is probably related to availability of these larger faster swimming fish to the survey gear. The Yankee-36 trawl has always had a tendency to under-sample large mackerel over the years, but for some unknown reason survey catches in the most recent years have been low or zero (Table B6). One explanation is that large mackerel have moved further offshore or south during recent cold winters. The average temperature in the spring survey during 2002-2004 was much below the average from the preceding decade (Figure B14). The commercial fishery in recent years has also caught few larger fish, but this may be explainable since the fishery has been narrowly focused in inshore areas off Rhode Island and New Jersey and apparently large fish have not been available in those areas (Figure B15). Commercial vessels have done little searching in offshore areas that are far removed from inshore fishing grounds that are close to ports. Therefore, to further address issues of scale and

goodness-of-fit caused by low survey and commercial landings of older fish, the CAA was aggregated at 7+. Preliminary model runs with a delay-difference biomass model (Schnute 1985) (biomass, age 2 and 3+) also indicated that aggregating over older age groups might be a useful approach. Emphasis coefficients for the base case model are listed in Table (B9). The working group decided that this was the best model formulation currently available for determining the status of the mackerel stock. Several additional sensitivity runs were examined by the WG and results are presented in subsequent pages. Results for the accepted base case run are as follows.

Total Biomass

Total biomass reached 1.9 million mt in 1969 and declined to just over 0.7 million mt in 1977 (Figure B16). Total biomass increased steadily to 1.4 million mt in 1999 and then increased rapidly to 2.9 million mt in 2004 (Figure B16). Total biomass ranged between 2.3 and 2.9 million mt during 2000-2004, averaging 2.5 million mt.

Spawning Biomass

Spawning biomass peaked in 1972 at 1.7 million mt, declined until 1976, and began to increase thereafter (Figure B17). During 1978-2000 spawning biomass increased steadily to 1.3 million mt in 2000. SSB continued to increase and then stabilized at 2.3 million mt in 2003-2004 (Figure B17). Spawning biomass ranged between 1.3 and 2.3 million mt in 2000-2004 and averaged 2.0 million mt.

Fishing Mortality

Fishing mortality was relatively high during 1969-1975, peaking at 0.54 in 1975 (Figure B18). Fishing rates dropped dramatically to a low of 0.05 in 1978 followed by a very low and stable period during 1979-1986. Fishing mortality reached a small peak in 1988 of 0.09, coincident with the joint venture (JV) fishery that operated for several years, and then declined to a low of 0.02 in 2000 (Figure B18). The average fishing rate during 2001-2004 was 0.04 and F in 2004 was 0.05.

Stock-Recruitment, Recruitment

Recruitment has been highly variable for the mackerel stock over a range of spawning biomass between about 0.3-2.3 million mt (Figure B19). Recruitment ranged between 0.1-5.8 billion fish during 1962-2004 and averaged 1.1 billion fish (Figure B20). There have been three large year classes during that period, the 1967, 1982, and 1999 year-classes (Figure B20). Recruitment from the 2002 and 2003 year-class appears promising, but is difficult to quantify at this time. The recent average recruitment during 2001-2004 was 1.6 billion fish and recruitment in 2004 was estimated at 2.8 billion.

Surplus Production

Biological reference points were estimated with a Fox model (Fox 1975), Schaefer model (Schaefer 1954) and from an internal B-H stock-recruitment relationship. Reference points from the B-H parameters were $MSY = 89,000$ t, $SSB_{msy} = 644,000$ t, and $F_{msy} = 0.16$. Surplus production (SP) in the mackerel stock was available sporadically during the 1962-2004 time-period (Figure B21). Periods of SP occurred before the ICNAF fishery in the late 1960s, during the early 1980s, and more recently in the late 1990s through 2003 (Figure B21). Results from the Schaefer and Fox models were not used because the surplus production (SP) data surfaces for both model was flat over a wide range of SSB, resulting in very high estimates of K and B_{msy} . Only the results from the B-H model were deemed to be useful by the committee. The average SP for this stock during 1962-2003 was 148,000 mt; this value can serve as a proxy upper bound on MSY for the current assessment.

Precision of ASAP Estimates

The relative precision of the estimates for spawning stock biomass and fishing mortality were calculated using the Hessian matrix from the ASAP model fitting procedure. This approach produces a mean and standard deviation for every parameter in the model (Table B12). Results indicate that estimates for both SSB and F are moderately precise. The estimated mean SSB was 2.32 million mt, ranging from 1.49-3.14 million mt, for a two standard deviation interval. The average estimate of F was 0.05, ranging from 0.035-0.063, again for a 2 SD interval. Results from an MCMC run of the ASAP model indicated that these 2SD intervals are comparable to a 95% CI.

Model Diagnostics

Plots of observed-predicted series for the spring NEFSC survey used to tune the ASAP model for trend were produced as a diagnostic measure of goodness of fit. Plots of observed vs. predicted data series (log scale) are shown in Figures (B22; B23) for the base case model. Survey observed and predicted series for the pre 1985 and post 1985 period track nicely with few indications of patterning. The committee examined all the available ASAP diagnostics such as age and year specific observed vs. predicted CAA, indices at age, effective sample size, stock-recruitment plot, and population by year, and concluded that these were also reasonable.

Retrospective Analysis

A retrospective analysis was conducted to observe if there are any patterned trends in SSB and recruitment of the ASAP base model. Results for SSB indicate a moderate pattern for 2001-2003 and larger difference for 2004 (Figure B24). There also appeared to be a change in trend for 2004. For recruitment there appears to be some consistent patterning for years prior to 1999. For the large 1999 year-class the pattern is not consistent among years, but estimates are highly variable across years (2000-2004) (Figure B25).

Projections

Natural mortality was set at $M=0.2$ for the projections. Partial recruitment to the fishery was set at 0.2 for age 1, 0.6 for age 2, and 1.0 for age 3 and older. Maturity was held constant at 0.2 at age 2 and 1.0 at age 3 and older. Mean weights used in the projections were held constant, the values used were for 2004 (Table B4).

Deterministic projections for 2006-2008 were conducted by inputting an estimated catch of 95,000 mt (209 million lbs) in 2005, a target fishing mortality of 0.12 (MAFMC 1998, $F_{\text{target}}=0.75 \times F_{\text{msy}}$) in 2006-2008, and annual recruitment values based on the S/R curve that was estimated from data. If 95,000 mt (209 million lbs) are landed in 2005, SSB in 2006 will increase to 2,640,210 mt (5.8 billion lbs) (Table B13). If the $F_{\text{target}} F=0.12$ is attained in 2006-2008, SSB will decline to 2,304,020 mt (5.1 billion lbs) in 2007 and to 2,043,440 mt (4.5 billion lbs) in 2008. Landings during 2006-2008 would be 273,290 mt (603 million lbs), 238,790 mt (527 million lbs), and 211,990 mt (467 million lbs), respectively (Table B13). These landings are the result of an unusually large year-class (1999) present in 2005, and will not be sustainable in the long term. It is expected that these projected landings will decline to MSY (89,000 mt (196 million lbs)) levels in the future when a more average recruitment condition exists in the stock.

8.0 SENSITIVITY ANALYSIS

An additional trial run was conducted to address the retrospective problem that occurred in the base run. It was assumed that there is still a great deal of variability in the model fit caused by the lack of older fish in the CAA and survey. Even aggregating the CAA and survey to 7+ did not appear to alleviate this problem fully. We therefore decided to allow the model to estimate selectivity during 1995-2004 in the fishery to see if this impacted the results. Emphasis coefficients for this model are listed in Table (B10). This approach changed and improved the retrospective pattern in SSB and recruitment. The retrospective for SSB appears to have been minimized as all the trajectories are consistent and there is no apparent pattern (Figure 1 App2). The retrospective pattern for recruitment also appears to be lessened, but there is still some sequential patterning for year-classes prior to 1999 and a clear pattern for the 1999 year-class (Figure 2 App2).

The working group also wanted to see an ASAP model run that included the NEFSC winter bottom trawl survey to compare the results to the VPA. SSB in this model run showed the familiar peak in biomass in the early 1970s, but this was followed by a steep decline in SSB to a low of 99,000 mt in 2004 (Figure 3 App2). This steep decline in SSB was the result of a very sharp increase in fishing mortality during the late 1990s and 2000-2004 (Figure 4 App2). The observed vs. predicted series for the winter (Figure 5 App2), and spring 1 (Figure 6 App2) were reasonable, but the pattern for the spring2 series deteriorated, with a series of negative residuals from 1990-2003 (Figure 7 App2). Adding the winter series to the ASAP model obviously caused the model fit to deteriorate seriously, producing infeasible trends in SSB and fishing mortality.

The final sensitivity run requested by the committee was a model that allowed selectivity to be estimated for the entire time-series from 1962-2004. This run was accomplished by using the same parameter setup as for the base case, but designating two separate time-blocks, one from 1962-1994 and the other from 1995-2004, and letting the model estimate fishery selectivity. In this run, SSB increased to over 1.6 million mt in 1972, declined sharply, and then steadily increased to about 1.4 million mt in 2004 (Figure 8 App2). As in several of the previous runs, fishing mortality peaked in the 1970s, declined, and remained low during the 1980s-2004. However, in this run F was much more asymptotic during the early years and then more dome shaped during the late 1990s, through 2004 (Figure 9 App2). The observed vs. predicted series for this model show that goodness of fit was reasonable with both the spring1 and spring2 series showing little patterning (Figure 10; 11 App2). The fishery selectivity for this model was asymptotic for the early years of the time-series and showed a moderate dome thereafter (Figure 12 App2).

9.0 SARC-30 RESEARCH RECOMMENDATIONS (TOR 6)

a. Explore logbook data for information on catch rates and geographic distribution.

No analysis was completed on this recommendation. Previous analyses have suggested that catch rates from the mackerel are an unreliable index of abundance because electronics are used to actively search for this species. Frequent technological improvements in winches, nets, doors, and other equipment also make it very difficult to compare fishery dependent catch rates among years. The fishery also tends to be aggregated in isolated small areas, piggybacked on the success of other vessels during the season. The recent and current fishery in the USA takes place along the inshore areas of New Jersey and Rhode Island depending on the location of mackerel on the continental shelf during winter. This factor means that very little information on the distribution of mackerel can probably be obtained from fishery dependent data.

b. Explore Canadian trawl survey indices for use in VPA calibrations.

Several additional trawl survey indices and egg indices were explored as tuning indices, but currently they do not appear useful in resolving assessment issues with this stock (Pers. comm. F. Gregoire DFO 2005)

c. Explore the feasibility of acoustic surveys for monitoring stock size.

Several attempts have been made to use acoustics to survey mackerel during recent winter cruises on the RV Delaware II. To date there has been little success, but this does not preclude the use of acoustics on this species, especially with the RV Bigelow in future.

d. Examine estimates of Z calculated from research vessel survey data with respect to their usefulness in estimating natural mortality.

No progress was made on this recommendation during the interim period.

10.0 RESEARCH RECOMMENDATIONS

- Currently there are historical age data that are only in hard copy form. These data should be put into an electronic database to allow examination of alternative methods, such as non-transformed indices.
- The current approach of transforming the survey indices should be expanded to include an exploratory analysis of geometric mean or other distributions instead of retransformed mean.
- Examine NEFSC Spring survey since 1999 to see what may have caused large increases in catch/tow.
- Explore use of environmental covariates to help explain recruitment deviations from the stock recruitment relationship.
- Consider the use of environmental variables to adjust the NEFSC Winter and Canadian surveys for changes in availability and consider their use as tuning indices in modeling.
- Increase sampling of commercial landings and survey catches to better characterize age and length composition.
- Conduct simulation exercises to determine the sample sizes required to detect old fish with high probability in commercial samples assuming they are present.
- Explore discard estimation, especially for years when large year classes are first entering the fishery.
- Pilot survey to explore for old fish to test hypothesis regarding dome in commercial fishery selectivity.

11.0 LITERATURE CITED

- Bigelow, H.B., and W.C. Schroeder. 2002. Fishes of the Gulf of Maine. Edited by B.C. Collette and G. Klein-MacPhee. Third edition. Smithsonian Institution Press, Washington D.C.
- Byrne, C.J., and J.R.S. Forrester. 1991. Relative fishing power of two types of trawl doors. NEFSC SAW/12. 7pp.
- DFO. 2004. Atlantic mackerel of the Northwest Atlantic in 2003. Department of Fisheries and Oceans, Canada. Stock Status Report 2004/018. 12 pp.
- Fox, W.W. 1975. Fitting the generalized stock production model by least squares and equilibrium approximation. US Fish Bulletin. 73:23-37.
- Grégoire, F., C. Levesque, J. Guerin, L. Hudon, and J. Lavers. 2003. Atlantic mackerel (*Scomber scombrus* L.) fishery and biology in NAFO Subarea 3 and 4 in 2002. DFO Canada Sci. Advis. Sec. Res. Doc. 2003/085. 36p.
- Grégoire, F. 2005. Update (September 2005) of the Atlantic mackerel (*Scomber scombrus* L.) landings in NAFO Subareas 3 and 4 in 2004. DFO Can. Sci. Advis. Sec. Res. Doc. 2005/057. 17pp.
- MAFMC. 1998. Amendment 8 to the Atlantic mackerel, squid, and butterfish fishery management plan. Mid-Atlantic Fishery management Council. October 1998. 351 p.
- Morse, W.W., M.P. Fahay, and W.G. Smith. 1987. MARMAP surveys of the continental shelf from Cape Hatteras, North Carolina, to Cape Sable, Nova Scotia (1977-1984). Atlas No. 2. Annual distribution patterns of fish larvae. NOAA Tech. Memo. NMFS-F/NEC-47, 215 pp.
- NEFMC 1998. Evaluation of existing overfishing definitions and recommendations for new overfishing definitions to comply with the Sustainable Fisheries Act. Overfishing Definition Review Panel. 179 p.

- Northeast Fisheries Science Center (NEFSC). 2000. Atlantic Mackerel. 30th Northeast Regional Stock Assessment Workshop (30th SAW). Consensus summary of assessments. Northeast Fisheries Science Center Reference Document 00-03:273-310.
- O'Brien, L, J. Burnett, and R.K. Mayo. 1993. Maturation of nineteen species of finfish off the northeast coast of the United States, 1985-1990. NOAA, NMFS, Tech. Rep. 113. 66p.
- Overholtz, W.J., J.S. Link, and L.E. Suslowicz. 2000. Consumption of important pelagic fish and squid by predatory fish in the northeastern USA shelf ecosystem with some fishery comparisons. *Ices Journal of Marine Science*. 57:1147-1159.
- Overholtz, W.J., L.D. Jacobson, G.D. Melvin, M. Cieri, M. Power, D. Libby, and K. Clark. 2004. Stock assessment of the Gulf of Maine- Georges Bank Atlantic herring complex. Northeast Fisheries Science Center Reference Document 04-06. 290 p.
- Schnute, J. 1985. A general theory for analysis of catch and effort data. *Can. J. Fish. Aquat. Sci.* 42: 414-429.
- Schaefer, M.B. 1954. Some aspects of the dynamics of populations important in the management of commercial fisheries. *Bulletin Inter-Tropical Tuna Commission*. 1:27-56.

MACKEREL TABLES.

Table B1. Commercial and Recreational landings (mt) of Atlantic mackerel for the USA, Canada, and other countries from NAFO SA 2-6 during 1960-2004

1 Landings by Canadian vessels (Commercial) or foreign countries (Foreign) in Canadian waters (SA 2-4)

2 Landings by USA vessels (Commercial), recreational sources (Recreational), or foreign countries (Foreign) in USA waters (SA5-6).

	Canada		USA			
Year	Commercial ¹	Foreign ¹	Commercial ²	Recreational ²	Foreign ²	Total
1960	5888	0	1396	2478	0	9762
1961	5458	11	1361	-	11	6841
1962	6901	64	938	-	175	8078
1963	6363	99	1320	-	1299	9081
1964	10786	174	1644	-	801	13405
1965	11185	405	1998	4292	2945	20825
1966	11577	1244	2724	-	7951	23496
1967	11181	62	3891	-	19047	34181
1968	11134	9720	3929	-	65747	90530
1969	13257	5379	4364	-	114189	137189
1970	15710	5296	4049	16039	210864	251958
1971	14942	9554	2406	-	355892	382794
1972	16254	6107	2006	-	391464	415831
1973	21619	16984	1336	-	396759	436698
1974	16701	27954	1042	-	321837	367534
1975	13544	22718	1974	5190	271719	315145
1976	15746	17319	2712	-	223275	259052
1977	20362	2913	1377	-	56067	80719
1978	25429	470	1605	-	841	28345
1979	30244	368	1990	3588	440	36630
1980	22136	161	2683	2364	566	27910
1981	19294	61	2941	3233	5361	30890
1982	16380	3	3330	666	6647	27026
1983	19797	9	3805	3022	5955	32588
1984	17320	913	5954	2457	15045	41689
1985	29855	1051	6632	2986	32409	72933
1986	30325	772	9637	3856	26507	71097
1987	27488	71	12310	4025	36564	80458
1988	24060	956	12309	3251	42858	83434
1989	20795	347	14556	1862	36823	74383
1990	19190	3854	31261	1908	30678	86891
1991	24914	1281	26961	2439	15714	71309
1992	24307	2417	11775	344	0	38843
1993	26158	591	4666	540	0	31955
1994	20564	49	8877	1705	0	31195
1995	17650	0	8479	1249	0	27378
1996	20364	0	16137	1416	0	37917
1997	21309	0	15400	1735	0	38444
1998	19334	0	14415	670	0	34419
1999	16561	0	12026	1335	0	29922
2000	13383	0	5646	1448	0	20477
2001	23868	0	12336	1538	0	37742
2002	34402	0	26452	1286	0	62140
2003	44475	0	34292	724	0	79491
2004	51444	0	53724	467	0	105635
2005	0	0	41234	0	0	41234

Table B2. USA sampling of Atlantic mackerel commercial and recreational landings during 1998-2004.

	Commercial Lengths		Ages-All Sources		Recreational Lengths
Year	Jan-June	July-Dec	Jan-June	July-Dec	
1998	1956		1901		615
1999	4297		920		979
2000	907		625		723
2001	2910	116	1333	91	778
2002	2264	197	1207	118	483
2003	2465	322	1061	121	606
2004	938	163	719	71	1347

Table B3. Atlantic mackerel catch-at-age (millions) for NAFO SA 2-6 during 1962-2004

Year	1	2	3	4	5	6	7	8	9	10+	Total
1962	16.1	2.8	15.2	3.8	1.2	1.6	1.4	0.8	0.4	0.4	43.7
1963	1.1	4.2	1.3	26.3	6.0	0.3	0.2	0.2	0.2	0.2	40.0
1964	12.9	7.0	4.1	4.0	19.4	4.1	3.9	0.7	0.8	0.2	57.1
1965	9.0	3.6	2.9	4.0	5.2	19.5	4.2	4.0	0.7	0.0	53.1
1966	24.0	11.5	5.3	2.6	4.7	7.9	21.8	0.5	0.2	0.0	78.5
1967	0.8	26.7	19.8	3.5	3.3	5.1	6.1	32.3	0.3	0.0	97.9
1968	141.4	61.5	59.3	38.1	14.3	6.6	0.7	1.0	6.1	0.1	329.1
1969	7.1	262.1	160.7	65.8	5.7	3.0	2.0	3.1	2.2	8.3	520.0
1970	193.5	54.5	522.1	162.9	27.6	7.0	5.3	9.9	10.0	6.6	999.4
1971	74.6	294.2	127.4	558.9	203.5	34.6	8.9	3.6	4.3	15.3	1325.3
1972	22.1	85.7	256.2	182.6	390.4	87.3	24.0	4.2	8.2	9.4	1070.1
1973	161.8	283.2	285.1	233.6	192.4	197.2	31.2	11.0	4.1	5.4	1405.0
1974	95.9	242.2	264.4	101.5	114.3	111.8	108.3	25.7	6.4	3.3	1073.8
1975	373.7	431.4	113.7	100.8	58.6	67.8	51.9	50.5	12.5	3.3	1264.2
1976	12.5	353.5	272.5	85.7	52.4	27.3	40.5	34.6	22.6	14.8	916.4
1977	2.0	27.0	101.0	54.0	12.0	9.9	5.6	6.3	3.8	4.2	225.8
1978	0.1	0.2	4.7	17.4	13.3	8.4	4.7	2.2	4.5	7.3	62.8
1979	0.4	0.6	1.3	7.1	18.6	13.1	6.2	2.6	2.2	6.5	58.6
1980	1.2	10.9	1.0	1.0	6.9	13.8	4.7	2.0	1.0	5.2	47.7
1981	16.1	7.1	9.2	1.4	2.0	6.1	11.7	4.9	2.5	3.5	64.5
1982	3.7	11.8	2.7	9.1	1.2	1.9	3.4	8.4	2.9	5.1	50.2
1983	2.2	15.3	6.5	1.9	7.0	0.7	1.2	5.5	10.2	6.5	57.0
1984	0.5	40.4	27.2	3.2	1.2	4.6	0.6	0.7	3.4	14.0	95.8
1985	3.4	1.9	135.7	33.4	2.7	0.8	3.2	0.3	0.5	11.4	193.3
1986	1.1	10.4	6.5	91.7	22.1	1.7	0.5	3.1	0.2	5.6	142.9
1987	9.7	14.2	13.3	7.5	106.9	17.5	2.6	0.4	2.1	3.8	178.0
1988	1.5	13.0	10.3	10.1	11.5	107.4	22.5	2.6	1.2	5.7	185.8
1989	1.9	14.0	11.0	7.4	6.8	2.3	85.7	4.3	0.8	1.7	135.9
1990	1.7	19.9	30.4	7.9	6.4	4.3	0.8	54.1	2.6	1.2	129.4
1991	1.4	12.6	55.2	23.9	6.1	3.9	3.3	1.0	27.3	1.2	136.0
1992	0.7	6.5	5.0	24.9	14.9	2.0	1.4	1.2	1.3	16.1	74.0
1993	1.1	8.8	10.9	6.1	16.4	8.9	1.9	0.8	1.1	8.4	64.5
1994	1.9	1.6	12.0	13.8	5.3	19.4	6.7	1.1	0.3	4.0	66.1
1995	11.9	20.7	2.7	9.5	8.2	3.2	10.3	3.2	0.3	0.9	71.0
1996	3.0	26.5	24.1	1.9	12.6	9.8	2.5	10.2	2.3	1.5	94.5
1997	6.9	22.0	23.4	11.1	1.1	8.5	6.8	2.8	7.2	1.9	91.6
1998	2.2	29.8	19.1	16.6	8.7	1.2	5.9	4.1	1.0	2.4	91.0
1999	1.7	6.5	23.3	14.1	9.2	4.8	1.4	2.9	2.0	1.3	67.2
2000	26.0	9.3	6.0	10.3	4.4	3.3	0.7	0.1	0.2	0.4	60.6
2001	8.6	74.9	23.3	7.3	9.6	2.3	2.1	0.7	0.2	0.3	129.4
2002	9.9	12.4	120.0	14.2	5.3	9.7	3.1	0.8	0.2	0.1	175.7
2003	9.6	23.5	26.4	121.8	14.0	5.0	4.9	0.3	0.0	0.0	205.5
2004	35.1	74.0	22.0	24.9	120.1	9.0	2.8	0.9	0.2	0.0	288.8

Table B4. Mean weight-at-age (USA and Canada, kg) for Atlantic mackerel during 1962-2004.

Year	1	2	3	4	5	6	7	8	9	10+
1962	0.130	0.208	0.289	0.365	0.433	0.491	0.541	0.581	0.614	0.657
1963	0.120	0.192	0.264	0.334	0.395	0.448	0.492	0.529	0.559	0.593
1964	0.116	0.188	0.262	0.332	0.395	0.450	0.495	0.533	0.564	0.588
1965	0.123	0.200	0.278	0.352	0.419	0.477	0.525	0.565	0.598	0.595
1966	0.128	0.209	0.294	0.374	0.447	0.509	0.562	0.605	0.641	0.595
1967	0.123	0.202	0.283	0.360	0.428	0.489	0.540	0.581	0.615	0.595
1968	0.148	0.241	0.335	0.425	0.506	0.576	0.634	0.683	0.722	0.753
1969	0.131	0.214	0.300	0.382	0.456	0.520	0.574	0.618	0.654	0.683
1970	0.107	0.179	0.253	0.324	0.389	0.444	0.491	0.530	0.562	0.596
1971	0.110	0.181	0.256	0.327	0.391	0.446	0.494	0.532	0.564	0.599
1972	0.123	0.210	0.300	0.386	0.464	0.533	0.590	0.638	0.677	0.723
1973	0.113	0.189	0.269	0.345	0.414	0.473	0.524	0.565	0.600	0.635
1974	0.111	0.190	0.273	0.352	0.425	0.487	0.541	0.585	0.621	0.655
1975	0.104	0.176	0.252	0.326	0.393	0.451	0.500	0.540	0.573	0.606
1976	0.097	0.168	0.244	0.316	0.382	0.440	0.489	0.530	0.563	0.592
1977	0.114	0.198	0.288	0.375	0.454	0.524	0.582	0.631	0.671	0.707
1978	0.192	0.285	0.425	0.463	0.509	0.582	0.625	0.659	0.673	0.713
1979	0.190	0.272	0.531	0.567	0.579	0.603	0.652	0.714	0.752	0.803
1980	0.146	0.376	0.548	0.609	0.617	0.635	0.672	0.705	0.781	0.777
1981	0.114	0.315	0.523	0.577	0.643	0.660	0.674	0.707	0.723	0.768
1982	0.152	0.340	0.541	0.606	0.666	0.743	0.737	0.722	0.719	0.775
1983	0.098	0.257	0.479	0.593	0.628	0.659	0.712	0.709	0.705	0.730
1984	0.098	0.162	0.338	0.525	0.625	0.657	0.696	0.715	0.705	0.716
1985	0.111	0.260	0.277	0.416	0.558	0.644	0.677	0.665	0.737	0.715
1986	0.079	0.234	0.349	0.366	0.452	0.581	0.640	0.729	0.777	0.740
1987	0.107	0.210	0.316	0.404	0.411	0.505	0.502	0.706	0.747	0.744
1988	0.100	0.222	0.343	0.408	0.453	0.484	0.584	0.694	0.755	0.770
1989	0.100	0.231	0.375	0.414	0.474	0.509	0.529	0.631	0.753	0.813
1990	0.138	0.224	0.336	0.449	0.487	0.527	0.609	0.570	0.644	0.742
1991	0.187	0.293	0.399	0.462	0.543	0.596	0.616	0.688	0.686	0.768
1992	0.163	0.270	0.378	0.420	0.477	0.522	0.579	0.639	0.642	0.655
1993	0.185	0.270	0.351	0.435	0.477	0.534	0.595	0.644	0.682	0.693
1994	0.158	0.232	0.318	0.399	0.492	0.520	0.587	0.629	0.705	0.665
1995	0.187	0.261	0.343	0.417	0.469	0.544	0.554	0.617	0.704	0.768
1996	0.218	0.254	0.354	0.481	0.482	0.552	0.596	0.644	0.692	0.684
1997	0.199	0.301	0.382	0.451	0.547	0.532	0.571	0.609	0.658	0.685
1998	0.149	0.250	0.373	0.482	0.535	0.560	0.592	0.604	0.656	0.682
1999	0.167	0.266	0.393	0.459	0.529	0.581	0.611	0.618	0.681	0.685
2000	0.200	0.231	0.322	0.443	0.530	0.585	0.614	0.674	0.693	0.678
2001	0.137	0.263	0.359	0.402	0.507	0.580	0.649	0.628	0.663	0.677
2002	0.138	0.220	0.344	0.430	0.471	0.563	0.599	0.645	0.707	0.677
2003	0.129	0.229	0.308	0.435	0.517	0.573	0.635	0.641	0.839	0.677
2004	0.179	0.226	0.342	0.387	0.480	0.501	0.607	0.698	0.572	0.677

Table B5. Stratified mean weight and number per tow (standard) of Atlantic Mackerel from the NEFSC spring bottom trawl survey during 1968-2005.

Year	Kg	Number
1968	5.609	70.869
1969	0.055	0.484
1970	2.2	9.356
1971	3.145	12.668
1972	1.542	8.49
1973	6.746	20.973
1974	0.656	2.241
1975	0.242	3.54
1976	0.254	1.8
1977	0.081	0.287
1978	0.345	0.97
1979	0.089	0.172
1980	0.202	0.559
1981	2.47	5.872
1982	0.854	5.167
1983	0.135	0.884
1984	2.611	16.228
1985	2.232	8.242
1986	1.264	4.178
1987	7.492	35.231
1988	4.133	16.792
1989	1.1	12.273
1990	1.548	10.748
1991	5.604	23.265
1992	4.705	24.275
1993	5.583	26.089
1994	5.987	38.638
1995	5.1	24.387
1996	11.101	40.887
1997	2.494	22.054
1998	3.378	25.11
1999	7.109	50.617
2000	6.934	70.357
2001	15.726	116.454
2002	7.65	35.201
2003	11.082	60.488
2004	8.088	110.683
2005	4.276	32.322

Table B6. Atlantic mackerel number per tow (ln retransformed) at age from the NEFSC Spring bottom trawl survey during 1968-2005

Year	1	2	3	4	5	6	7	8	9	10+
1968	12.9400	0.4150	0.1894	0.0523	0.0164	0.0000	0.0000	0.0000	0.0000	0.0000
1969	0.0297	0.1418	0.0167	0.0058	0.0003	0.0007	0.0005	0.0009	0.0004	0.0004
1970	0.2795	0.1845	1.3910	0.6115	0.1812	0.0617	0.0549	0.0877	0.0827	0.0473
1971	0.3282	0.9409	0.4383	1.1250	0.3929	0.0621	0.0141	0.0073	0.0062	0.0083
1972	0.8719	0.3077	0.5929	0.2261	0.3254	0.0583	0.0112	0.0011	0.0018	0.0004
1973	0.3514	0.3398	0.1758	0.2338	0.1262	0.2846	0.1821	0.1524	0.0460	0.1022
1974	0.3478	0.1796	0.2358	0.0478	0.0985	0.0599	0.2084	0.0912	0.0590	0.0232
1975	0.6544	0.2298	0.0409	0.0226	0.0064	0.0073	0.0043	0.0039	0.0034	0.0000
1976	0.0959	0.3871	0.0710	0.0135	0.0024	0.0006	0.0028	0.0004	0.0019	0.0006
1977	0.0095	0.0472	0.0850	0.0453	0.0154	0.0052	0.0028	0.0070	0.0038	0.0139
1978	0.0502	0.1097	0.1032	0.1943	0.0958	0.0284	0.0110	0.0027	0.0148	0.0177
1979	0.0105	0.0037	0.0072	0.0126	0.0495	0.0144	0.0103	0.0057	0.0057	0.0482
1980	0.0234	0.1877	0.0066	0.0048	0.0233	0.0489	0.0110	0.0107	0.0070	0.0284
1981	0.3355	0.1371	0.4294	0.0476	0.0463	0.1613	0.4041	0.2302	0.1385	0.4021
1982	0.4323	0.1950	0.0215	0.0979	0.0182	0.0102	0.0245	0.0965	0.0440	0.0836
1983	0.2357	0.2873	0.0222	0.0016	0.0036	0.0006	0.0002	0.0014	0.0022	0.0020
1984	0.2598	1.8014	0.6055	0.0415	0.0050	0.0432	0.0036	0.0025	0.0161	0.0837
1985	0.3382	0.0846	1.8513	0.2348	0.0277	0.0107	0.0469	0.0032	0.0097	0.1864
1986	0.1301	0.4497	0.0778	0.5908	0.1177	0.0080	0.0014	0.0196	0.0004	0.0474
1987	1.4842	1.7945	0.8742	0.3719	2.9450	0.4967	0.1427	0.0156	0.1383	0.2560
1988	0.6336	0.4577	0.3666	0.3357	0.3748	1.7688	0.4428	0.0513	0.0478	0.2232
1989	1.5826	1.6407	0.0707	0.2841	0.0087	0.0108	0.0666	0.0086	0.0050	0.0182
1990	1.3003	1.3849	0.5010	0.0157	0.0129	0.0059	0.0004	0.0762	0.0094	0.0157
1991	1.6697	0.8891	1.4843	0.5374	0.2400	0.1144	0.0578	0.0000	0.2685	0.0027
1992	2.6984	2.3787	0.5585	1.0531	0.6272	0.1155	0.1321	0.0312	0.0449	0.2983
1993	0.9331	2.2477	0.9019	0.6031	0.9864	0.4515	0.1389	0.0915	0.2184	0.6286
1994	4.1386	1.7436	2.1139	0.8699	0.2534	0.5039	0.1133	0.0512	0.0105	0.2267
1995	3.1701	3.4871	0.5893	1.1824	0.7122	0.2848	0.7191	0.2258	0.0451	0.1351
1996	4.0058	3.2257	1.3258	0.1481	0.6175	0.4196	0.1927	0.2800	0.1456	0.1220
1997	3.0378	1.1619	0.4485	0.2247	0.0254	0.1244	0.1149	0.0452	0.0702	0.0159
1998	5.6955	3.1199	0.6787	0.2863	0.1211	0.0171	0.0867	0.0633	0.0179	0.0240
1999	5.0097	4.1347	2.9205	0.9221	0.4061	0.1784	0.0498	0.0819	0.0389	0.0191
2000	14.8080	2.4561	1.1156	0.7272	0.2514	0.1189	0.0500	0.0000	0.0194	0.0239
2001	12.4610	26.5960	1.7581	0.3622	0.2115	0.0375	0.0114	0.0093	0.0042	0.0012
2002	1.2662	2.9770	5.7418	0.4438	0.1229	0.0493	0.0192	0.0014	0.0000	0.0000
2003	9.1159	8.3906	2.9148	3.2997	0.4028	0.1207	0.0555	0.0000	0.0000	0.0000
2004	21.9190	3.0060	0.3165	0.1166	0.1516	0.0121	0.0010	0.0000	0.0000	0.0000
2005	1.7745	3.7293	0.9319	0.1697	0.1354	0.3667	0.0258	0.0050	0.0000	0.0000

Table B7. Weight and number per tow (standard) number per tow from the NEFSC winter bottom trawl survey during 1992-2005.

Year	Kg	Number
1992	14.813	47.694
1993	4.265	17.263
1994	0.254	1.161
1995	27.125	74.658
1996	6.828	40.034
1997	3.139	20.792
1998	4.123	18.332
1999	1.675	13.254
2000	1.342	4.676
2001	4.238	25.285
2002	5.528	25.609
2003	24.262	103.576
2004	5.042	59.469
2005	32.047	245.577

Table B8. Number of Atlantic mackerel per tow at age (retransformed) from the NEFSC Winter bottom trawls survey during 1992-2005.

Year	1	2	3	4	5	6	7	8	9	10+
1992	3.0523	1.4908	0.5367	1.6471	1.2904	0.3196	0.4615	0.1702	0.3949	2.1468
1993	0.7766	3.4136	0.9937	0.3717	0.9014	0.6192	0.1061	0.1033	0.249	0.3242
1994	0.3244	0.1053	0.2362	0.1387	0.0284	0.066	0.0116	0.0043	0	0.0043
1995	1.6475	4.0829	0.12502	2.0966	1.693	0.9592	2.0291	0.9036	0.2251	0.5583
1996	3.6854	2.4076	0.9712	0.1034	0.5132	0.3334	0.1294	0.2284	0.0864	0.0235
1997	2.1225	2.0327	1.5196	0.6153	0.0429	0.2684	0.2356	0.1026	0.1556	0.0283
1998	1.7823	2.8163	0.8565	0.6274	0.3459	0.076	0.1595	0.2664	0.0381	0.1187
1999	1.2908	0.6953	0.8	0.2662	0.1451	0.0802	0.0253	0.0498	0.0147	0.0164
2000	0.3437	0.8842	0.5921	0.4236	0.1798	0.0954	0.0365	0	0.01	0.0377
2001	2.0193	2.9817	0.5373	0.2485	0.3259	0.0922	0.0507	0.0282	0.011	0.0012
2002	1.871	0.7383	0.0269	0.412	0.1711	0.169	0.0633	0.009	0	0.0005
2003	15.955	4.4698	2.0118	2.4065	0.5303	0.3372	0.2546	0.0452	0	0
2004	11.334	2.1515	0.2461	0.2624	0.6209	0.0871	0.0102	0.001	0.001	0
2005	34.691	38.056	3.822	0.5594	0.4275	1.0818	0.0235	0.0122	0	0

Table B9. Likelihood components and emphasis coefficients in ASAP base case model run

Likelihood Component	Lambda
Landings	1000
SR relationship	1
Spring survey	6.74
Recruitment CV	0.5
CAA	50

Table B10. Likelihood components and emphasis coefficients in ASAP model run to address retrospective patterning

Likelihood Component	Lambda
Landings	1000
SR relationship	10
Fishery Selectivity	10
Spring survey	6.74
Recruitment CV	0.5, and 0.01 in 2000&2004
CAA	50

Table B11. Likelihood results for various model components for preliminary, base case, and sensitivity runs of the ASAP model.

ASAP model runs					Sensitivity model runs		
	spring only	spring split	spring split	Base	winter &	retro	est selectivity
			SR on	Case	spring	fix 95-04	62-94, 95-04
obj_fun	4327.18	3943.78	2499.00	1580.08	3241.43	1692.53	1540.11
Catch_Fleet_Total	3.17	2.57	1.03	0.50	6.78	0.60	0.99
CAA_proportions	1048.16	998.27	317.64	254.81	310.93	350.87	211.44
Index_Fit_Total	3275.85	2942.94	2075.09	1221.98	2777.30	1253.53	1219.76
Winter					597.87		
Spring no split	3275.85						
Spring1 split		1657.48	1150.56	653.71	1199.72	685.56	655.31
Spring2 split		1285.46	924.53	568.27	979.71	567.97	564.46

Table B12. Parameter file from ASAP base case model run with parameter name, parameter estimate (value), and standard deviation (std)

index	name	value	std
1	log_Fmult_year1	-3.15E+00	1.41E-01
2	log_Fmult_devs	1.20E-01	3.91E-02
3	log_Fmult_devs	2.65E-01	3.82E-02
4	log_Fmult_devs	8.42E-02	3.65E-02
5	log_Fmult_devs	1.59E-01	4.05E-02
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7	log_Fmult_devs	1.59E-01	5.49E-02
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9	log_Fmult_devs	4.10E-01	3.68E-02
10	log_Fmult_devs	4.85E-01	3.43E-02
11	log_Fmult_devs	6.78E-02	3.40E-02
12	log_Fmult_devs	4.07E-01	3.50E-02
13	log_Fmult_devs	5.72E-02	3.61E-02
14	log_Fmult_devs	6.77E-02	3.88E-02
15	log_Fmult_devs	-8.90E-02	4.21E-02
16	log_Fmult_devs	-1.29E+00	3.86E-02
17	log_Fmult_devs	-1.00E+00	3.45E-02
18	log_Fmult_devs	2.05E-02	3.33E-02
19	log_Fmult_devs	-2.58E-01	3.48E-02
20	log_Fmult_devs	1.34E-01	3.57E-02
21	log_Fmult_devs	-1.11E-01	3.60E-02
22	log_Fmult_devs	-6.07E-02	4.09E-02
23	log_Fmult_devs	-5.93E-02	4.00E-02
24	log_Fmult_devs	4.25E-01	3.90E-02
25	log_Fmult_devs	-1.07E-01	3.33E-02
26	log_Fmult_devs	3.52E-01	3.35E-02
27	log_Fmult_devs	3.09E-01	3.46E-02
28	log_Fmult_devs	-2.14E-01	3.61E-02
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30	log_Fmult_devs	-7.82E-02	3.65E-02
31	log_Fmult_devs	-6.40E-01	3.39E-02
32	log_Fmult_devs	-6.99E-02	3.56E-02
33	log_Fmult_devs	7.39E-02	3.38E-02
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35	log_Fmult_devs	3.07E-01	3.45E-02
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39	log_Fmult_devs	-5.82E-01	3.76E-02
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110	SSB	3.02E+02	4.11E+01
111	SSB	3.16E+02	4.26E+01
112	SSB	3.36E+02	4.46E+01
113	SSB	3.70E+02	4.55E+01
114	SSB	4.45E+02	4.55E+01
115	SSB	8.31E+02	6.16E+01
116	SSB	1.36E+03	6.49E+01
117	SSB	1.60E+03	6.67E+01
118	SSB	1.65E+03	6.52E+01
119	SSB	1.70E+03	7.37E+01
120	SSB	1.23E+03	5.92E+01
121	SSB	9.38E+02	5.33E+01
122	SSB	7.23E+02	4.37E+01
123	SSB	6.63E+02	4.49E+01
124	SSB	6.77E+02	6.12E+01
125	SSB	7.82E+02	7.51E+01
126	SSB	8.03E+02	7.80E+01
127	SSB	7.98E+02	7.70E+01
128	SSB	7.74E+02	7.46E+01
129	SSB	7.79E+02	7.46E+01
130	SSB	8.59E+02	8.11E+01
131	SSB	1.09E+03	1.05E+02
132	SSB	1.36E+03	1.37E+02
133	SSB	1.30E+03	1.39E+02
134	SSB	1.15E+03	1.29E+02
135	SSB	1.07E+03	1.29E+02
136	SSB	9.62E+02	1.26E+02
137	SSB	1.03E+03	1.42E+02
138	SSB	1.25E+03	1.79E+02
139	SSB	1.27E+03	1.91E+02
140	SSB	1.16E+03	1.77E+02
141	SSB	1.08E+03	1.68E+02
142	SSB	1.06E+03	1.66E+02
143	SSB	1.14E+03	1.82E+02
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165	recruits	2.16E+03	1.88E+02
166	recruits	5.22E+02	6.44E+01
167	recruits	1.65E+02	2.35E+01
168	recruits	1.09E+02	1.63E+01
169	recruits	4.93E+02	6.42E+01
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171	recruits	4.23E+02	6.15E+01
172	recruits	1.24E+03	1.65E+02
173	recruits	3.41E+03	4.01E+02
174	recruits	2.65E+02	4.54E+01
175	recruits	2.16E+02	3.89E+01
176	recruits	2.91E+02	5.12E+01
177	recruits	2.85E+02	5.02E+01
178	recruits	8.28E+02	1.31E+02
179	recruits	1.28E+03	1.99E+02
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181	recruits	7.71E+02	1.31E+02
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184	recruits	6.91E+02	1.21E+02
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186	recruits	6.52E+02	1.18E+02
187	recruits	9.38E+02	1.69E+02
188	recruits	6.48E+02	1.21E+02
189	recruits	8.07E+02	1.52E+02
190	recruits	5.04E+03	9.36E+02
191	recruits	1.09E+03	2.22E+02
192	recruits	8.04E+02	1.79E+02
193	recruits	1.76E+03	4.21E+02
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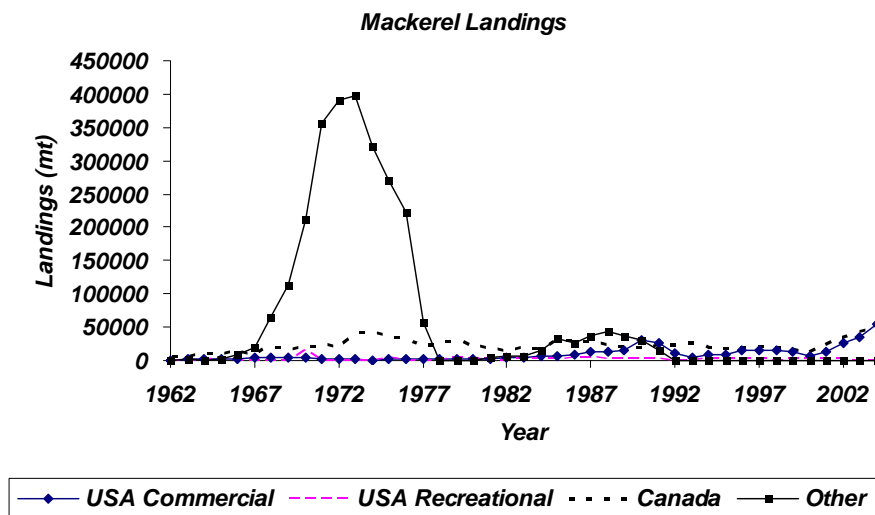
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226	plus_group	6.02E+02	9.93E+01
227	plus_group	6.74E+02	1.12E+02
228	plus_group	8.51E+02	1.42E+02
229	plus_group	8.12E+02	1.37E+02
230	plus_group	8.39E+02	1.45E+02
231	plus_group	8.58E+02	1.51E+02
232	plus_group	7.38E+02	1.33E+02
233	plus_group	7.66E+02	1.39E+02
234	plus_group	8.19E+02	1.49E+02
235	plus_group	8.27E+02	1.51E+02
236	plus_group	9.06E+02	1.67E+02
237	plus_group	8.85E+02	1.65E+02
238	MSY	8.95E+01	0.00E+00
239	SSB_ratio	7.79E+00	1.58E+00
240	proj_SSB_ratio	6.85E+00	0.00E+00
241	SSmsy_ratio	3.61E+00	6.42E-01
242	Fmsy_ratio	3.08E-01	0.00E+00
243	MSYp	8.95E+01	0.00E+00

Table B13. Projection for SSB (000 mt) and landings (000 mt) during 2006-2008 for the northwest Atlantic stock of mackerel.

Year	SSB	F	Land
2005	2450.68	0.04	95.00
2006	2640.21	0.12	273.29
2007	2304.02	0.12	238.79
2008	2043.44	0.12	211.99

MACKEREL FIGURES

A.



B.

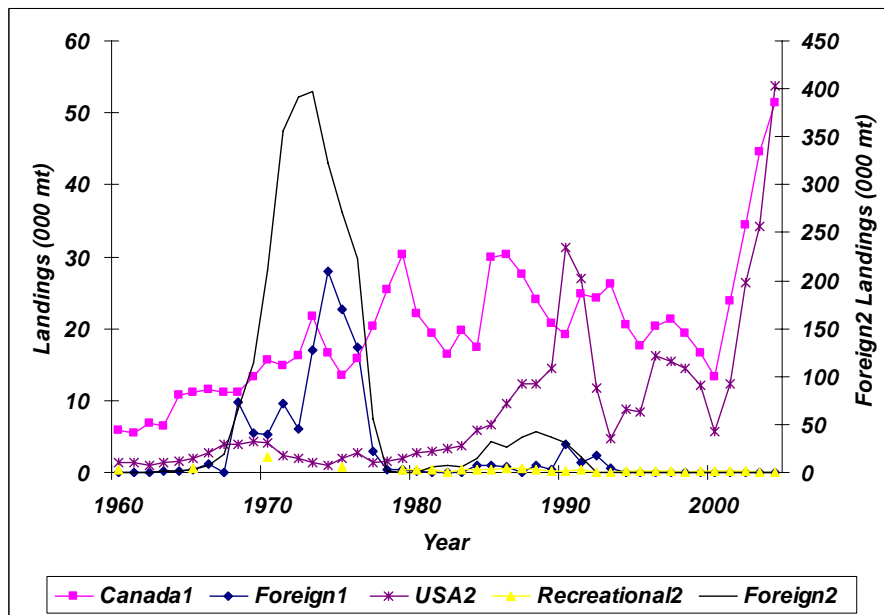


Figure B1. **A.** Landings of Atlantic mackerel in NAFO SA 2-6 during 1962-2004 by USA commercial, USA recreational, Canada, and other countries. **B.** Landings by Canadian vessels (Canada1) or foreign countries (Foreign1) in Canadian waters (SA 2-4). Landings by USA vessels (USA2), recreational sources (Recreational2), or foreign countries (Foreign2) in USA waters (SA5-6).

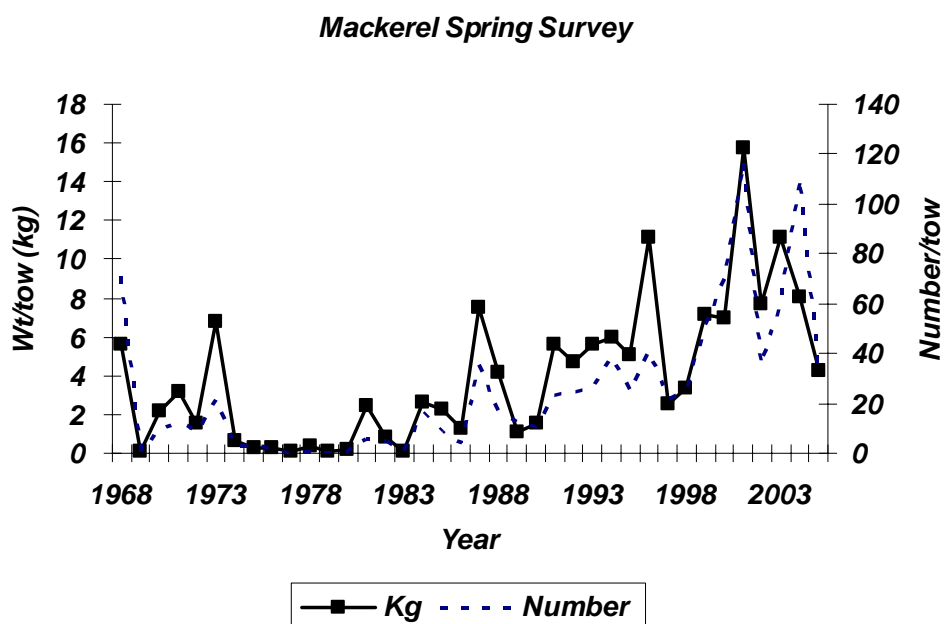


Figure B2. Mackerel Spring bottom trawl survey indices in wt/tow and number/tow during 1968-2005.

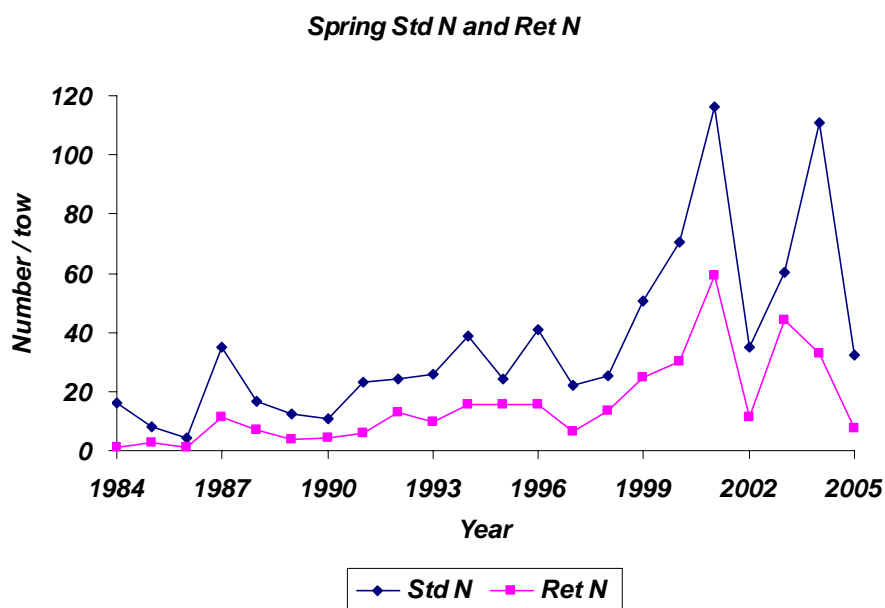


Figure B3. Mackerel Spring bottom trawl survey indices number/tow (standard-std and log retransformed-ret) during 1984-2005.

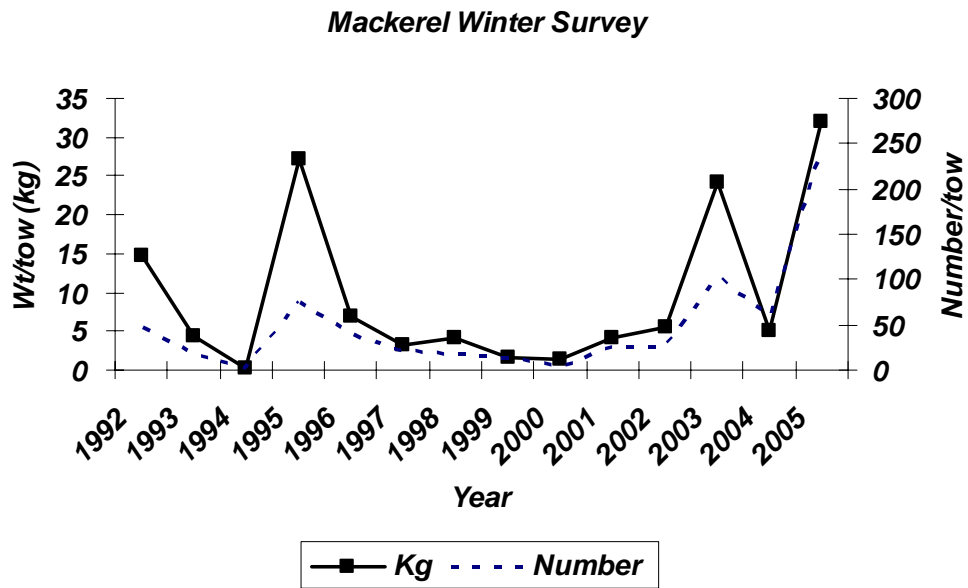


Figure B4. Mackerel winter bottom trawl survey indices in wt/tow and number/tow during 1992-2005.

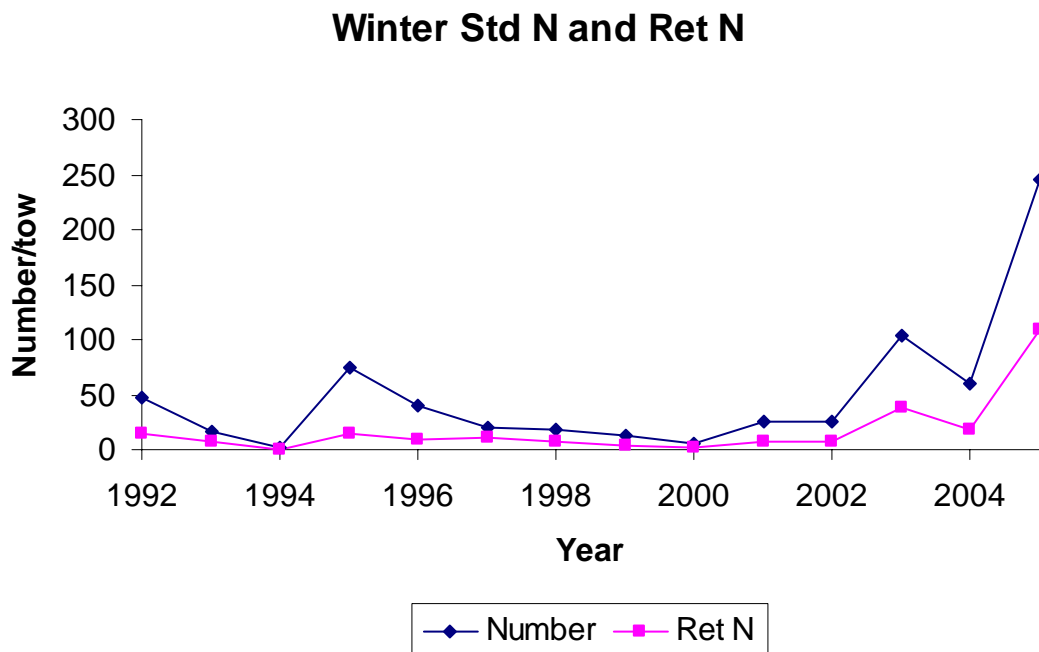


Figure B5. Mackerel winter survey indices in number/tow (standard-std and log retransformed-ret) during 1992-2005.

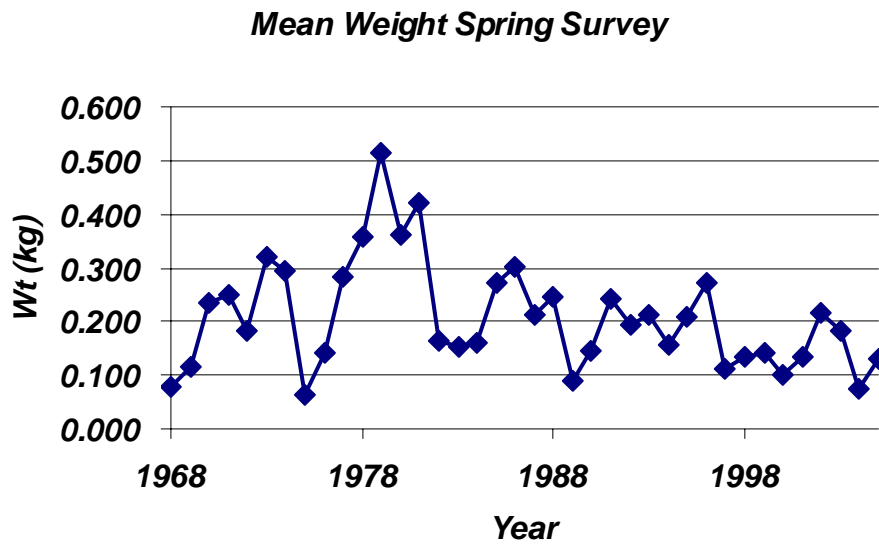


Figure B6. Average weight (kg) of Atlantic mackerel from NEFSC spring surveys during 1968-2005.

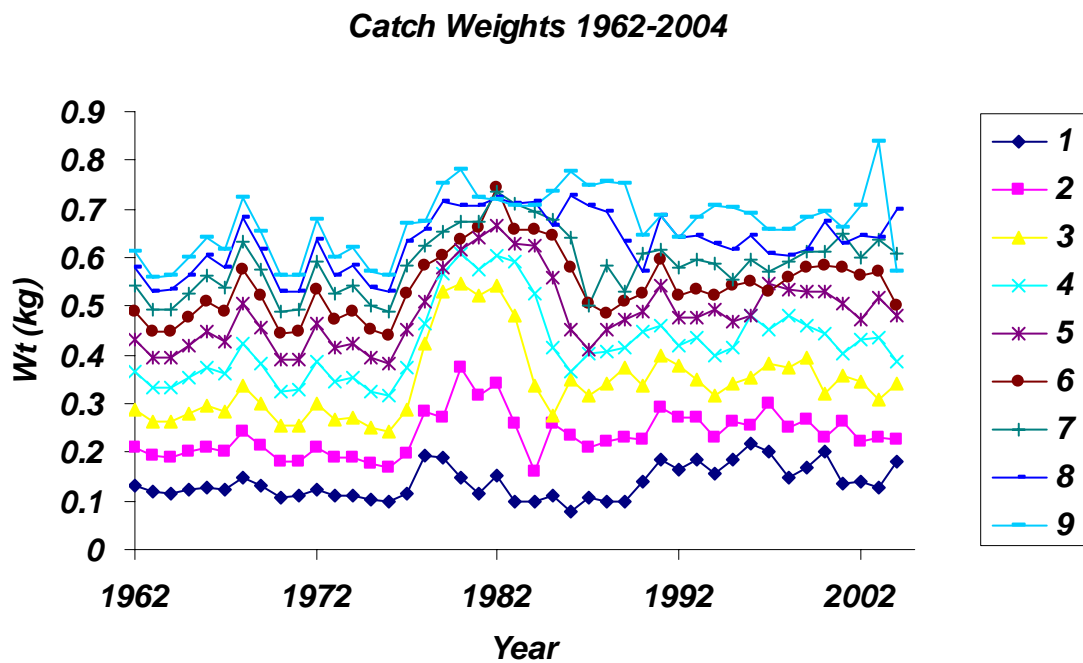


Figure B7. Landed weight (kg) of Atlantic mackerel from USA and Canadian fisheries in NAFO SA 2-6 during 1962-2004.

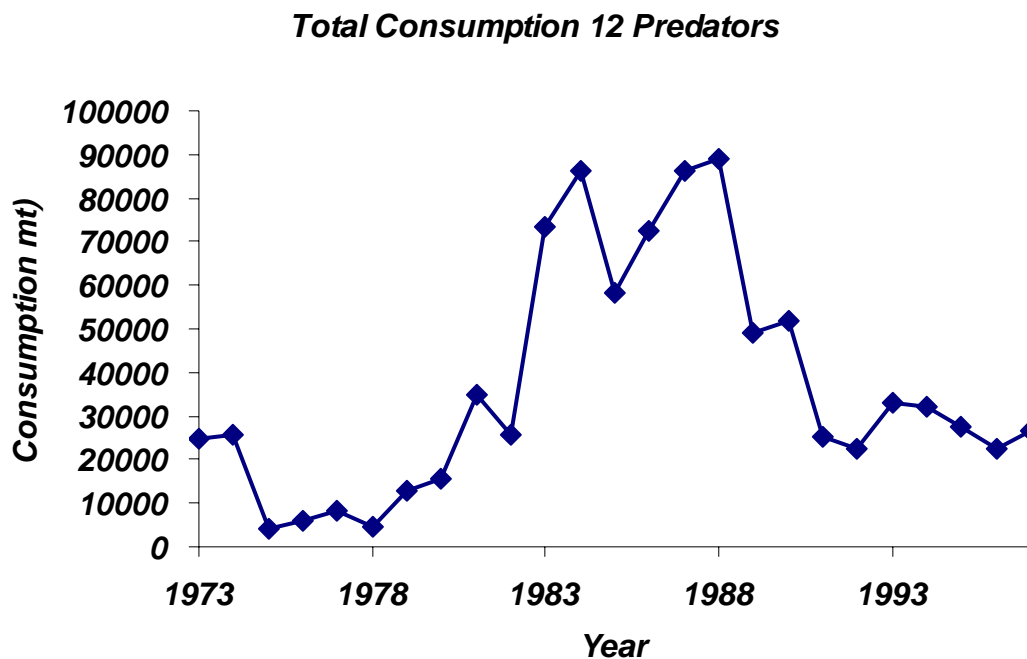


Figure B8. Consumption of Atlantic mackerel by 12 picivorous fish in the Mid-Atlantic-gulf of Maine region during 1973-1997.

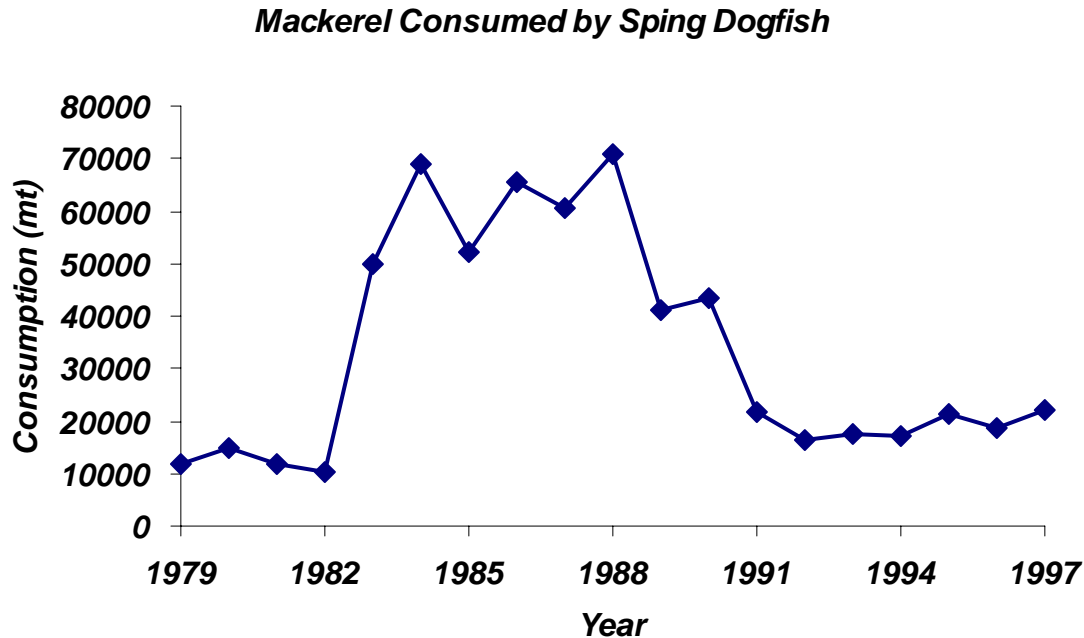


Figure B9. Consumption of Atlantic mackerel by spiny dogfish in the Mid-Atlantic-Gulf of Maine region during 1979-1997.

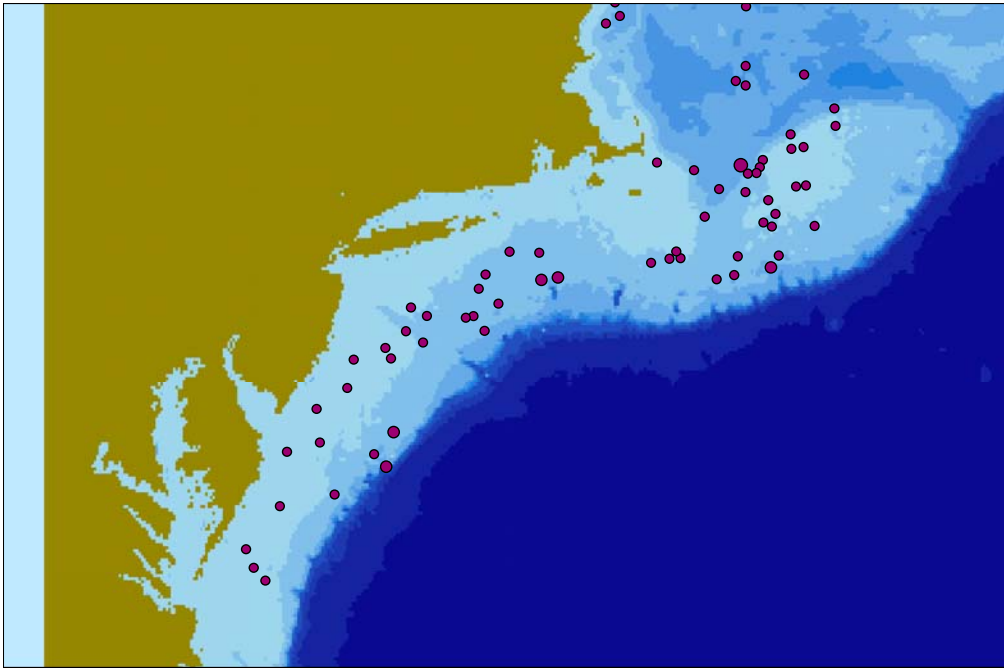


Figure B10. Distribution of mackerel during the spring NEFSC bottom trawl survey in 2002.

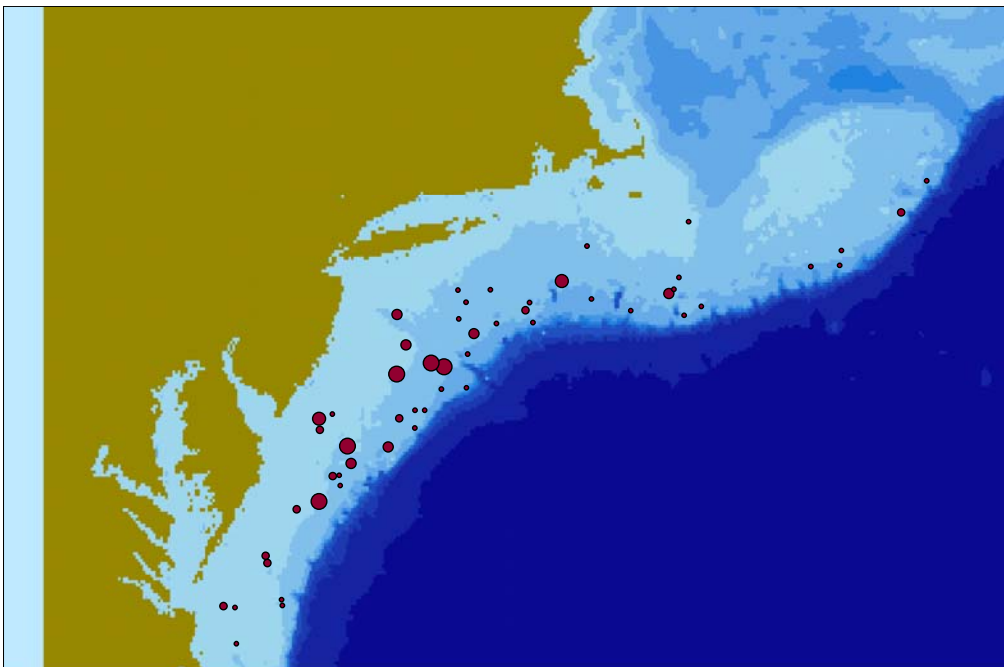


Figure B11. Distribution of mackerel during the spring NEFSC bottom trawl survey in 2003.

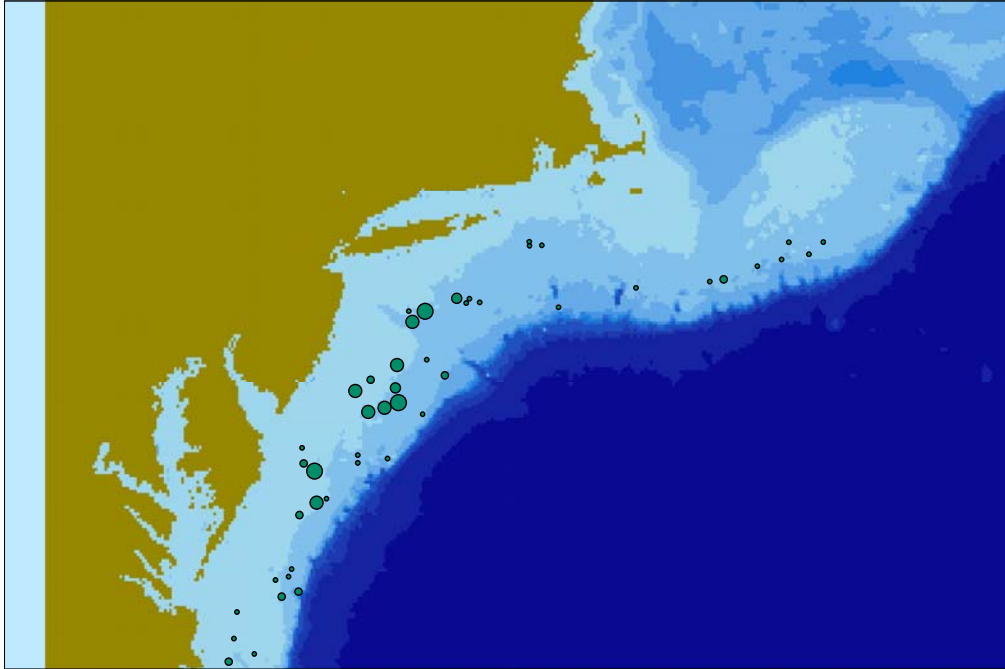


Figure B12. Distribution of mackerel during the spring NEFSC bottom trawl survey in 2004.

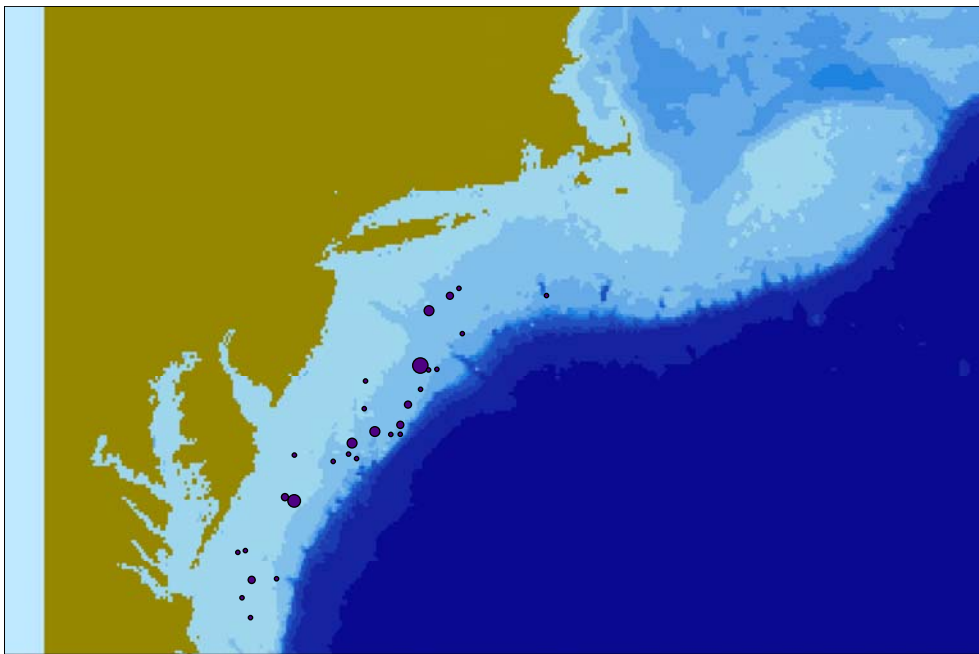


Figure B13. Distribution of mackerel during the spring NEFSC bottom trawl survey in 2005.

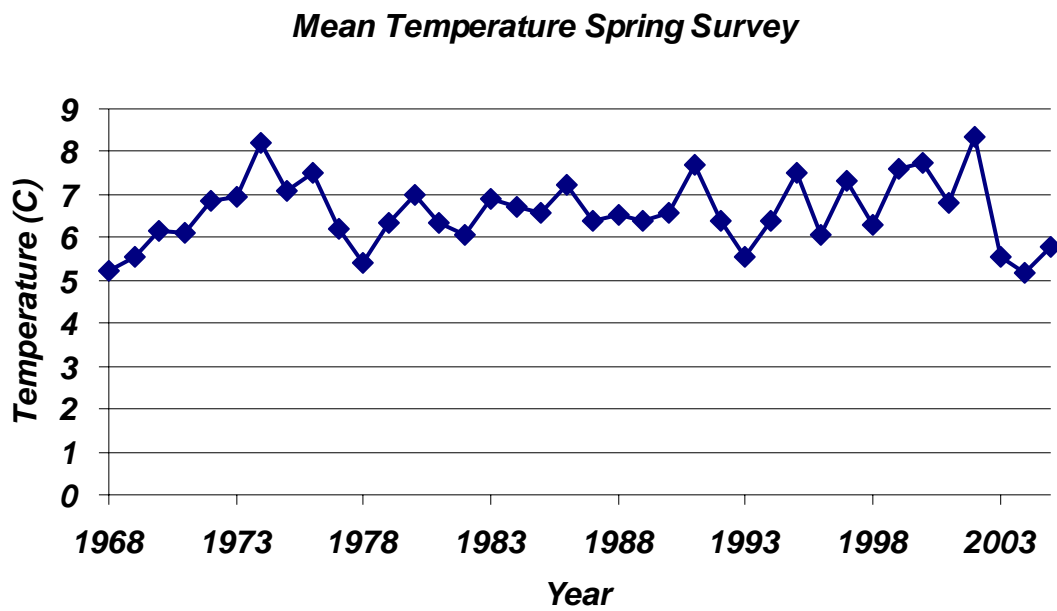


Figure B14. Average temperature from the NEFSC spring survey during 1968-2005.

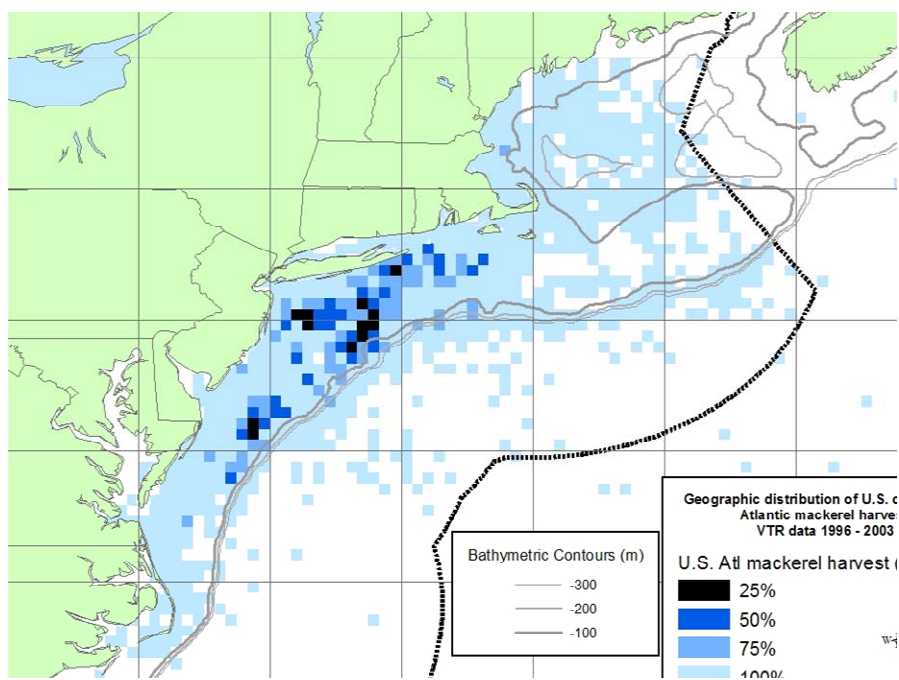


Figure B15. Map of fishing activity for mackerel during 1996-2003.

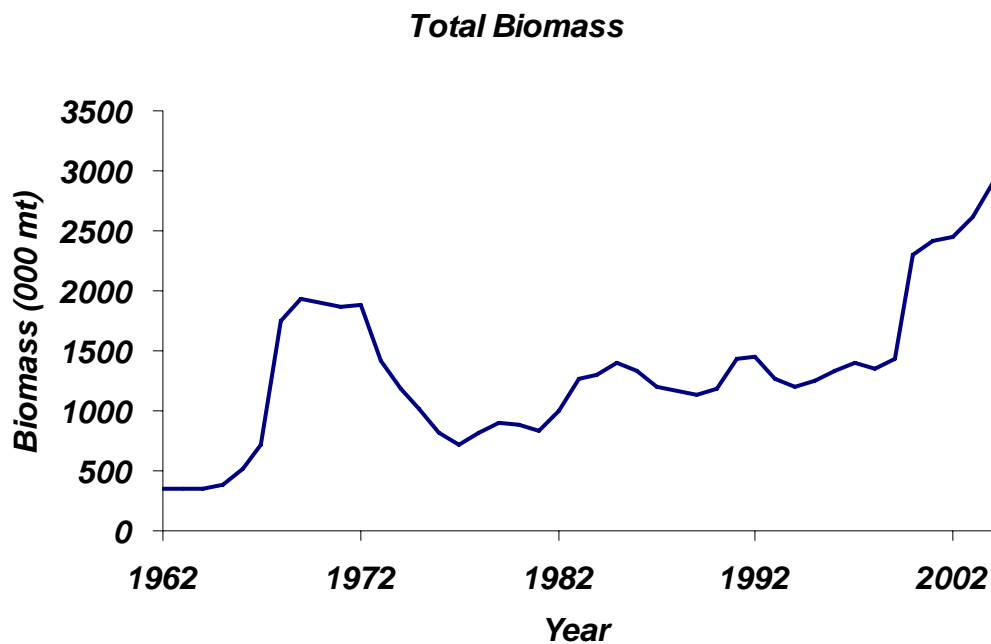


Figure B 16. Total biomass for Atlantic mackerel during 1962-2004 from the ASAP base model run.

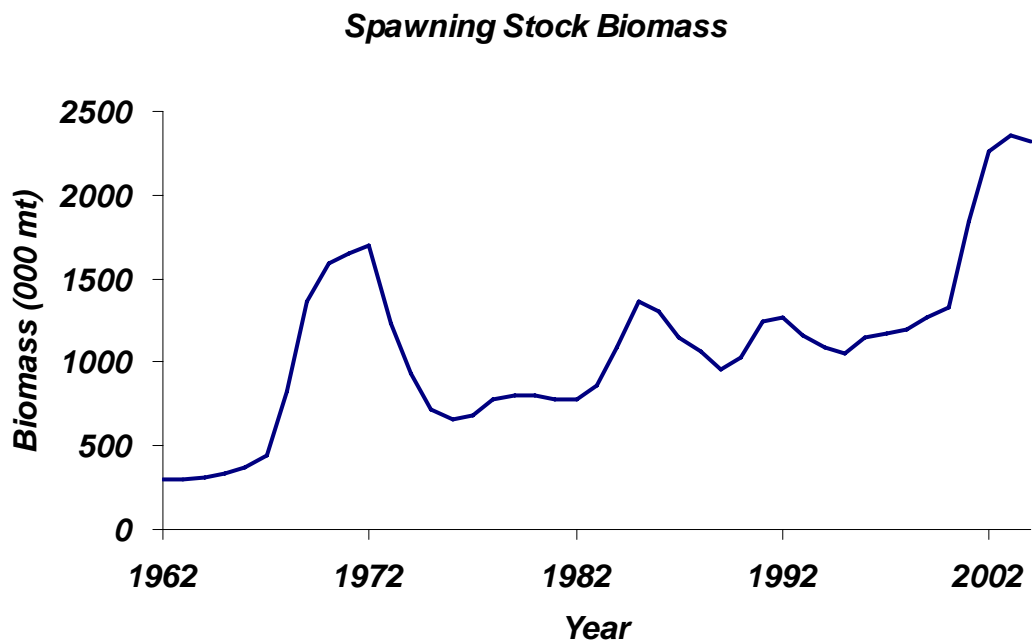


Figure B17. Spawning stock biomass for Atlantic mackerel during 1962-2004 from the ASAP base model run.

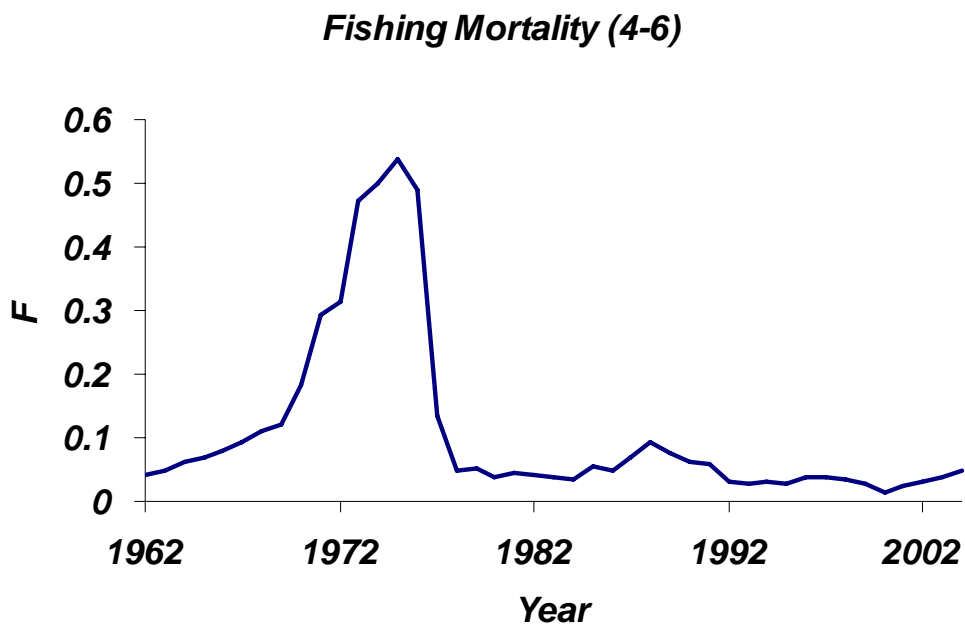


Figure B18. Fishing mortality for Atlantic mackerel during 1962-2004 from the ASAP base model run.



Figure B19. Stock recruitment for Atlantic mackerel during 1962-2004 from the ASAP base model run

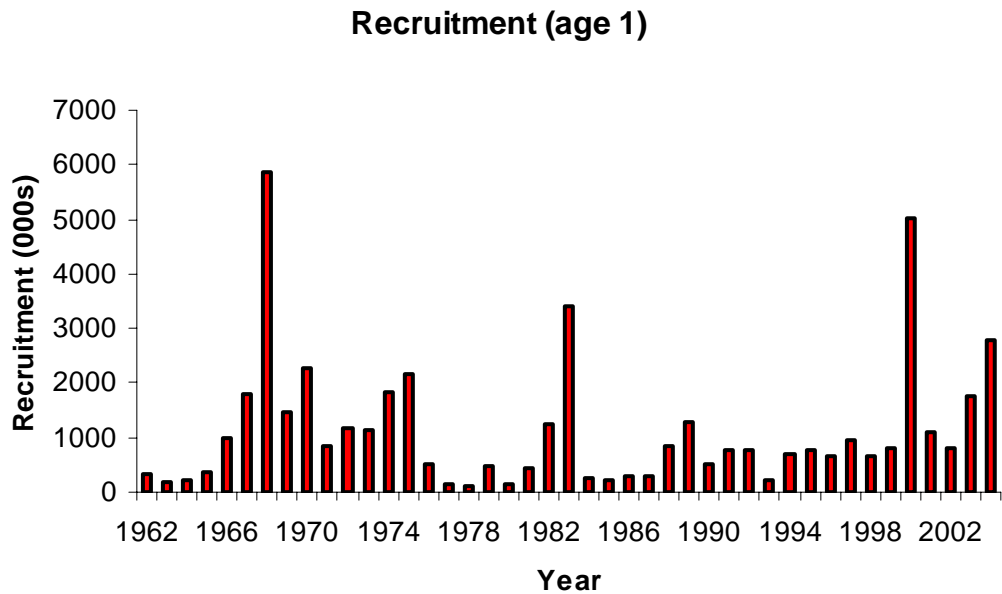


Figure B20. Recruitment (age 1) for Atlantic mackerel during 1962-2004 from the ASAP base model run.

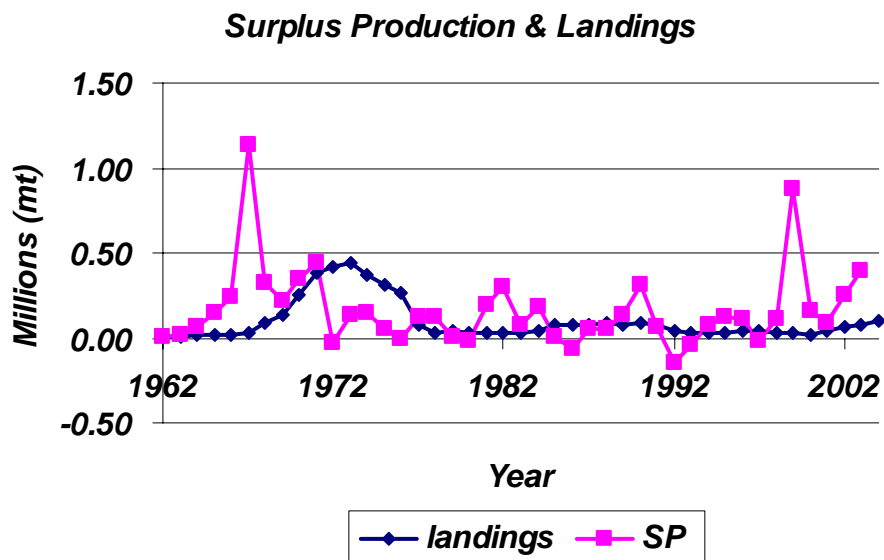


Figure B21. Surplus production and landings of Atlantic mackerel during 1962-2004 from the ASAP base model run.

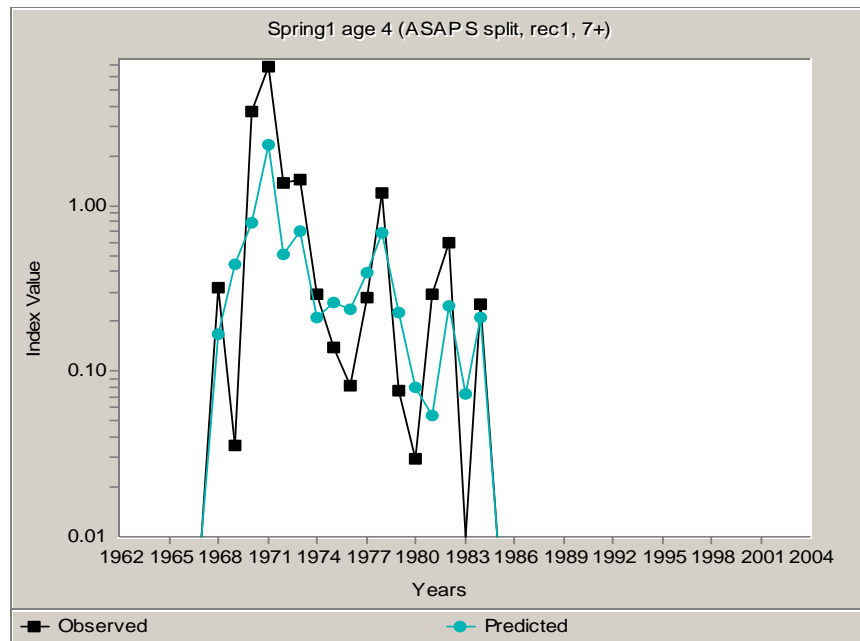


Figure B22. Spring survey observed vs. predicted series (1968-1984, age 4) for the base case ASAP model with the spring survey split in 1985, B-H SR model ($\lambda = 1$), and ages aggregated to 7+.

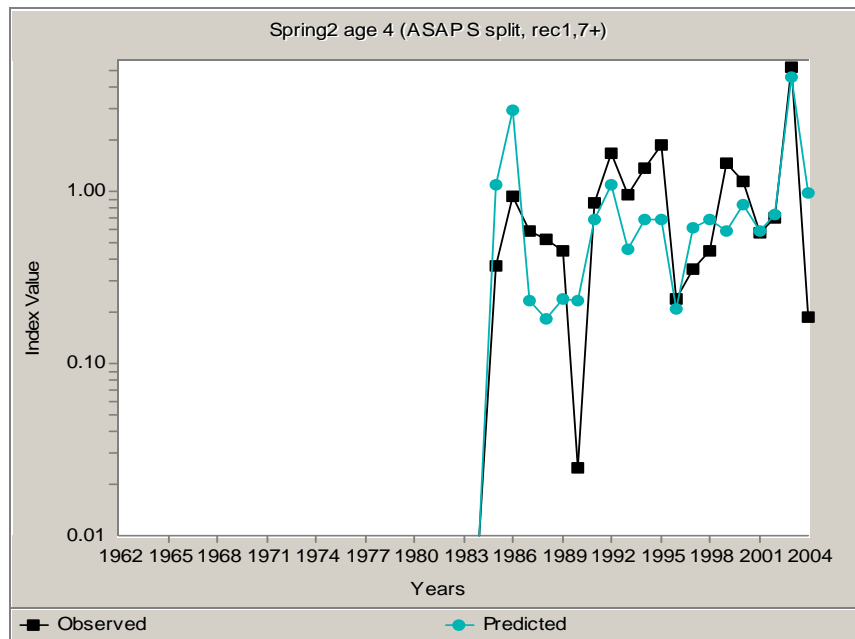


Figure B23. Spring survey observed vs predicted series (1985-2004, age 4) for the base case ASAP model with the spring survey split in 1985, B-H SR model ($\lambda = 1$), and ages aggregated to 7+.

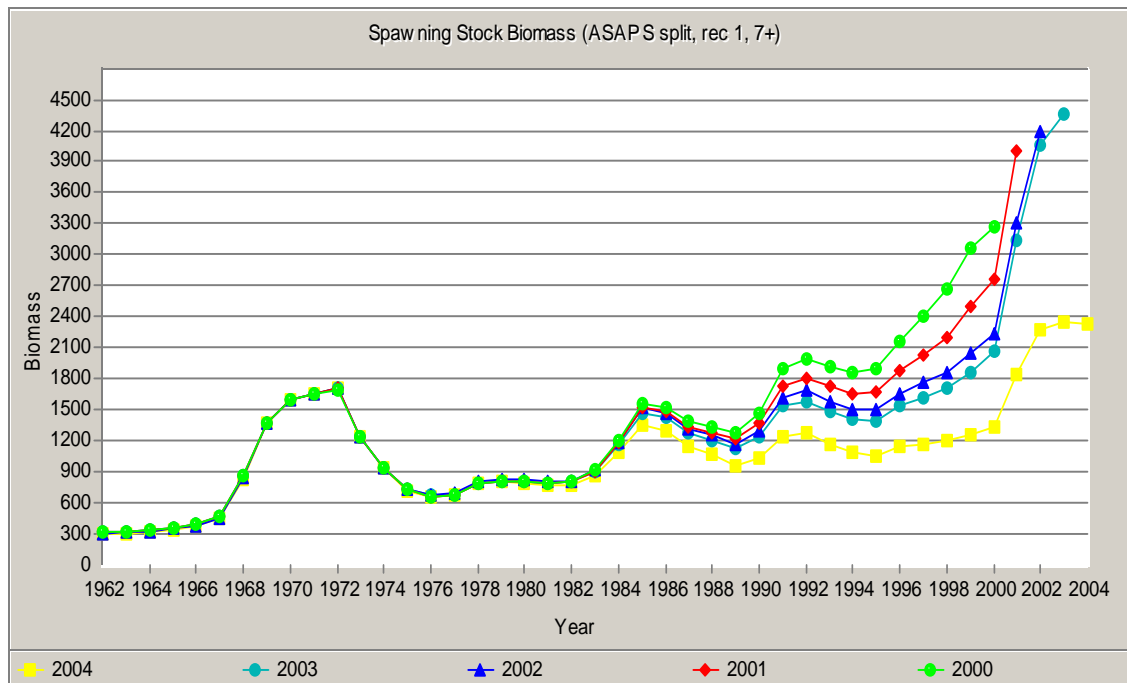


Figure B24. Retrospective pattern for SSB for the base case ASAP model with the spring survey split in 1985, B-H SR model ($\lambda = 1$), and ages aggregated to 7+.

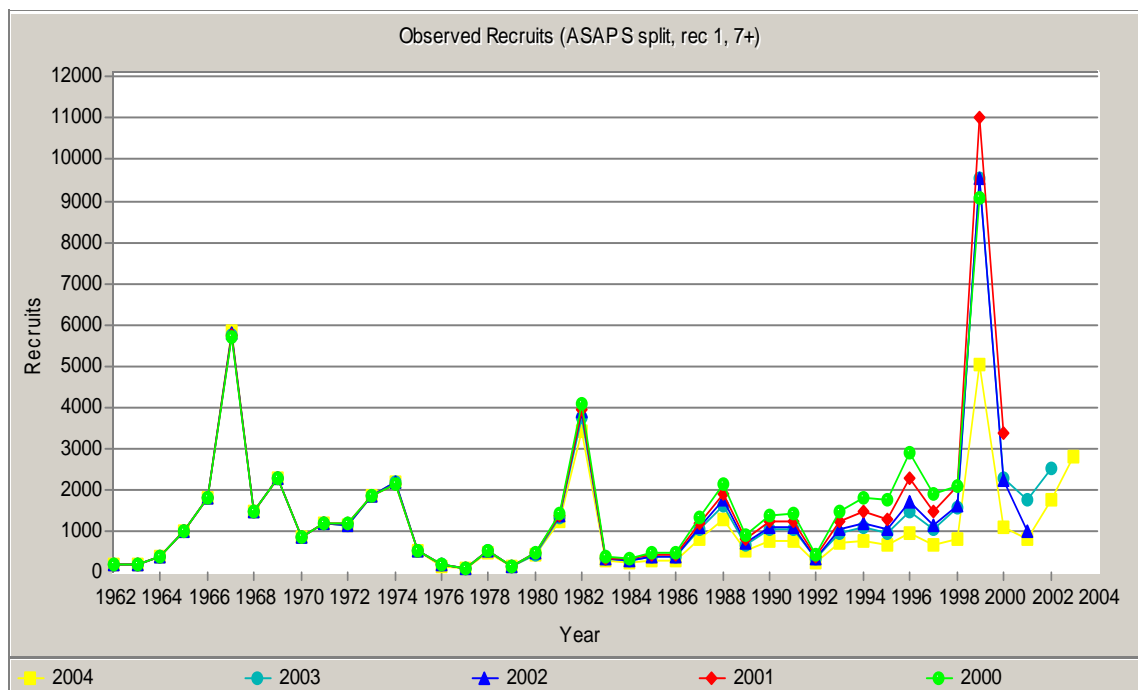


Figure B25. Retrospective pattern for recruitment for the base case ASAP model with the spring survey split in 1985, B-H SR model ($\lambda = 1$), and ages aggregated to 7+.

APPENDIX B1: Trial runs for the VPA and ASAP models.

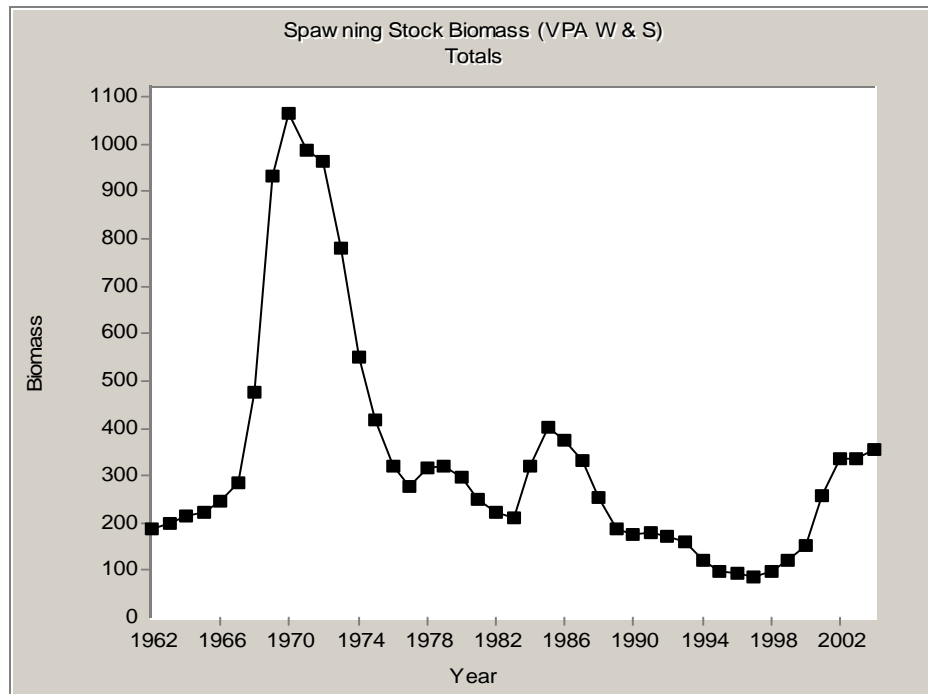


Figure 1 (APPENDIX B1). Spawning stock biomass for a VPA trial run with the winter and spring survey indices.

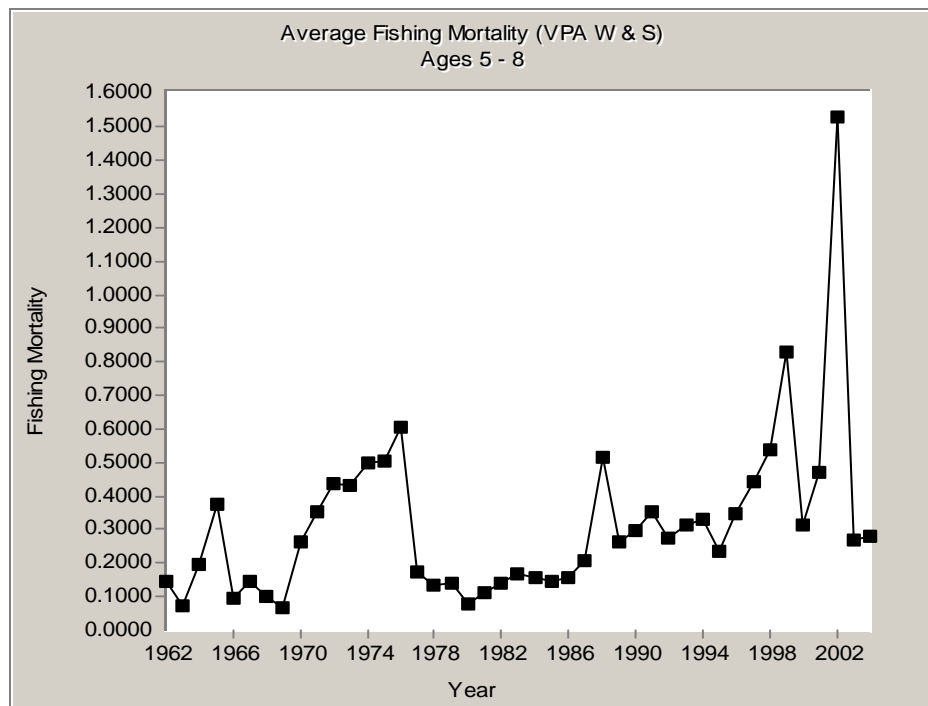


Figure 2 (APPENDIX B1). Fishing mortality for a VPA trial run with the winter and spring indices.

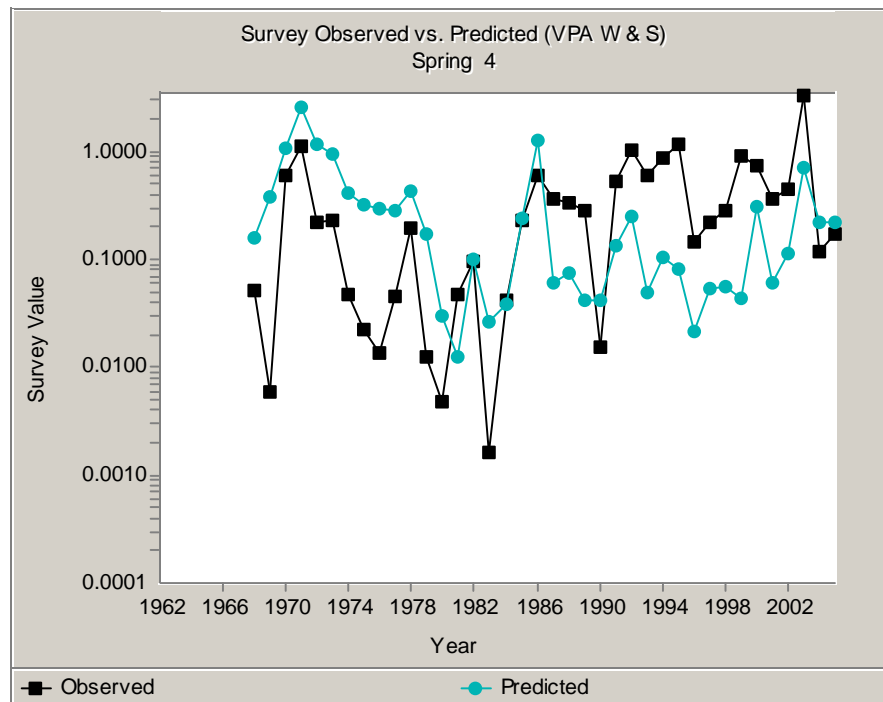


Figure 3 (APPENDIX B1). Spring survey observed vs. predicted series (age 4) for a VPA trial run with the winter and spring survey indices.

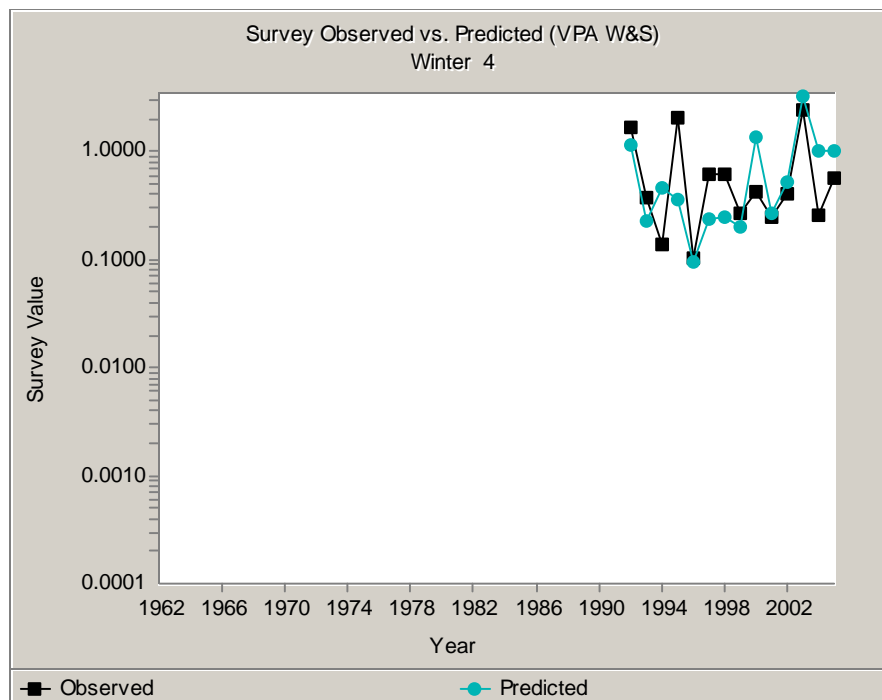


Figure 4 (APPENDIX B1). Winter survey observed vs. predicted series (age 4) for a VPA trial run with the winter and spring survey indices.

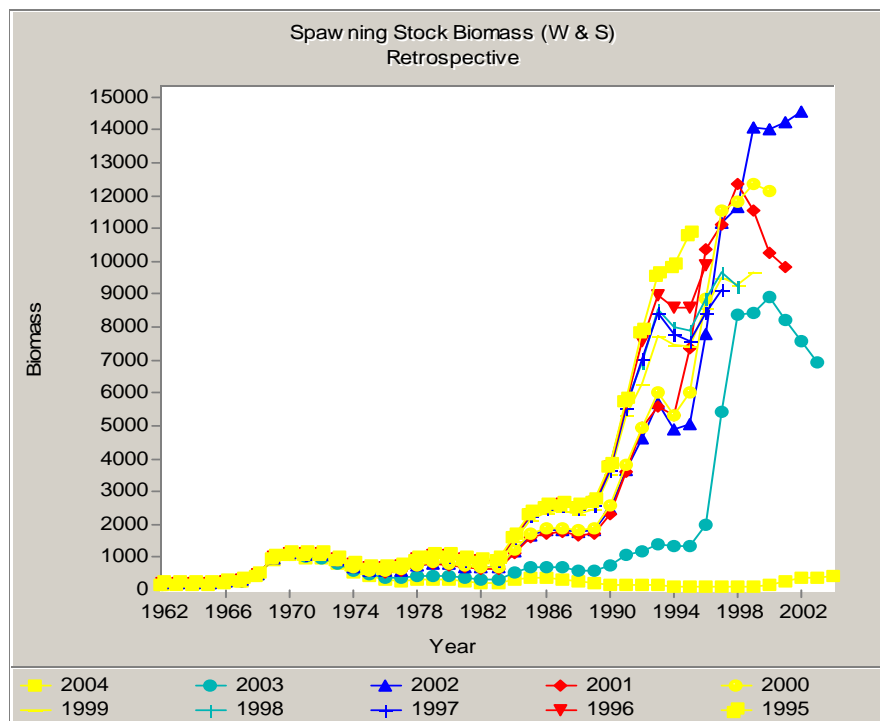


Figure 5 (APPENDIX B1). Retrospective pattern for SSB for a VPA trial run with the winter and spring survey indices.

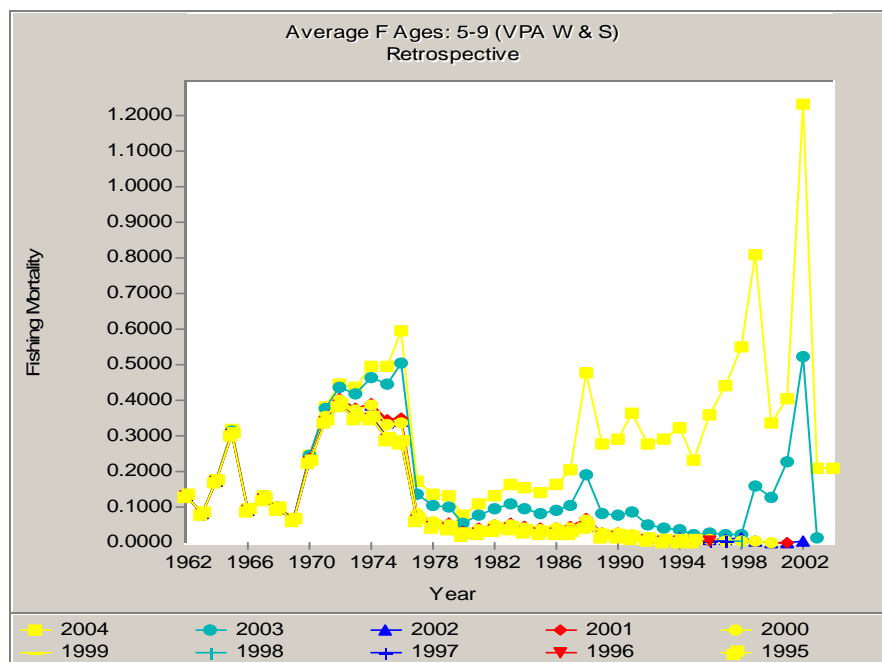


Figure 6 (APPENDIX B1). Retrospective pattern for SSB for a VPA trial run with the winter and spring survey indices.

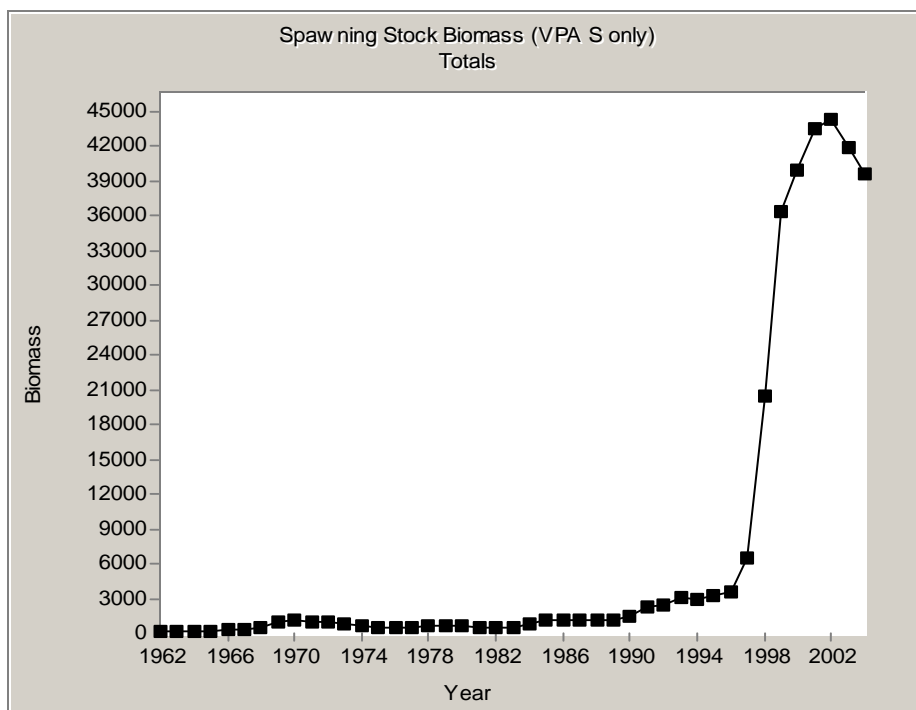


Figure 7 (APPENDIX B1). Spawning stock biomass for a VPA trial run with the spring survey indices.

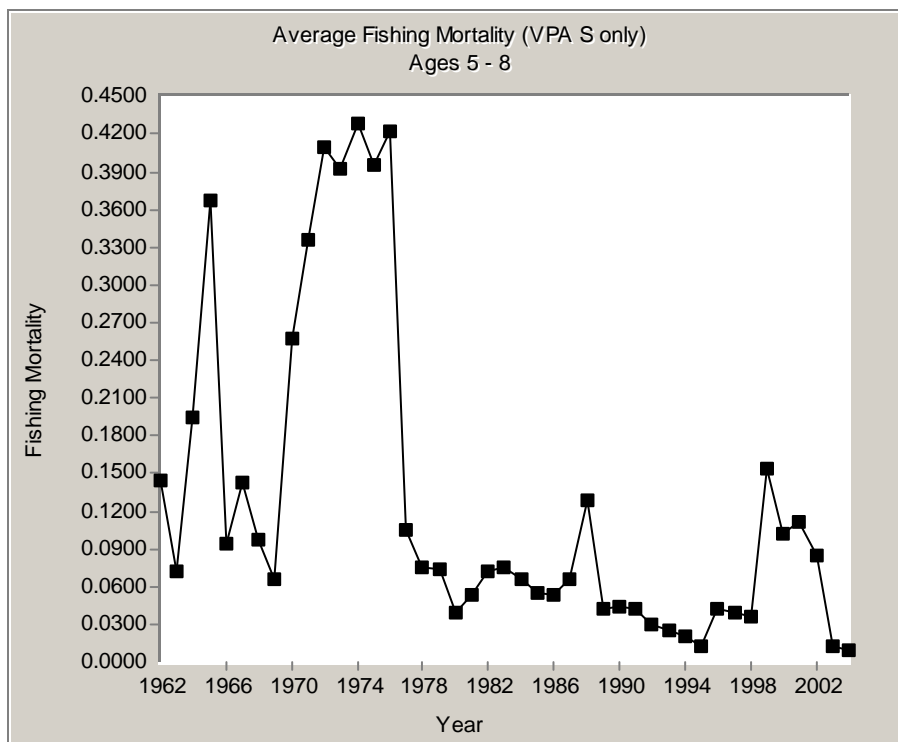


Figure 8 (APPENDIX B1). Fishing mortality for a VPA trial run with the spring survey indices.

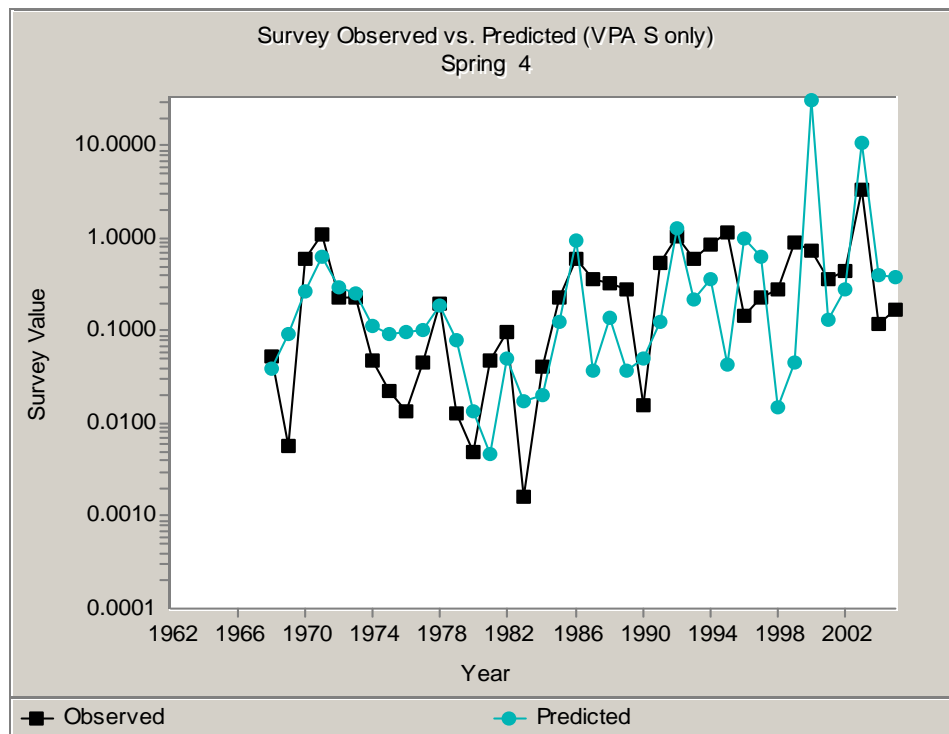


Figure 9 (APPENDIX B1). Spring survey observed vs. predicted series (1968-2004, age 4) for a VPA trial run with the spring survey indices.

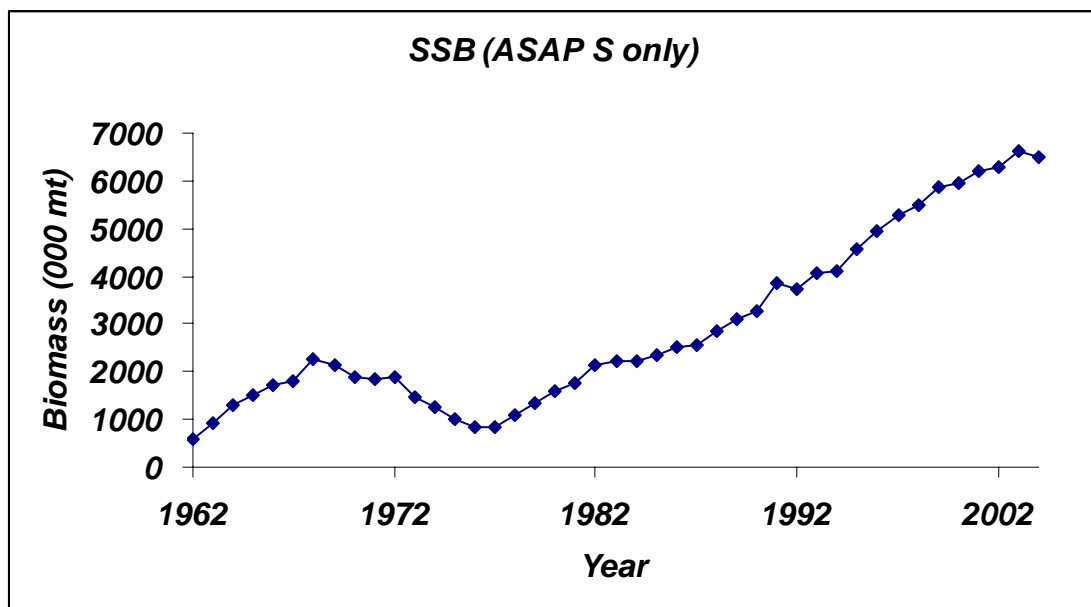


Figure 10 (APPENDIX B1). Spawning stock biomass for an ASAP trial run with the spring survey only.

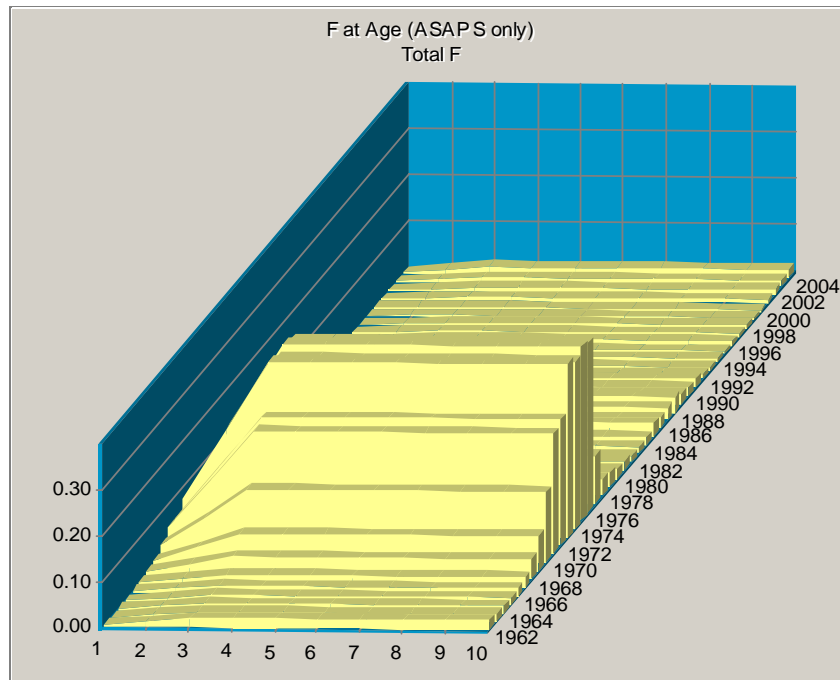


Figure 11 (APPENDIX B1). Fishing mortality by age and year for an ASAP trial run with the spring survey only.

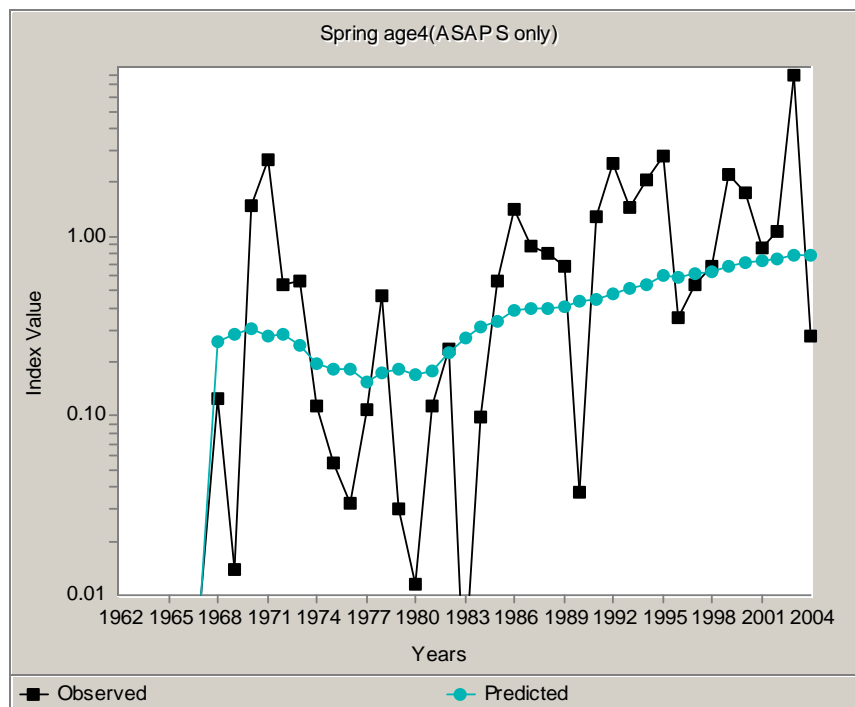


Figure 12 (APPENDIX B1). Spring survey observed vs. predicted series (1968-2004, age 4) for an ASAP trial run with the spring survey only.

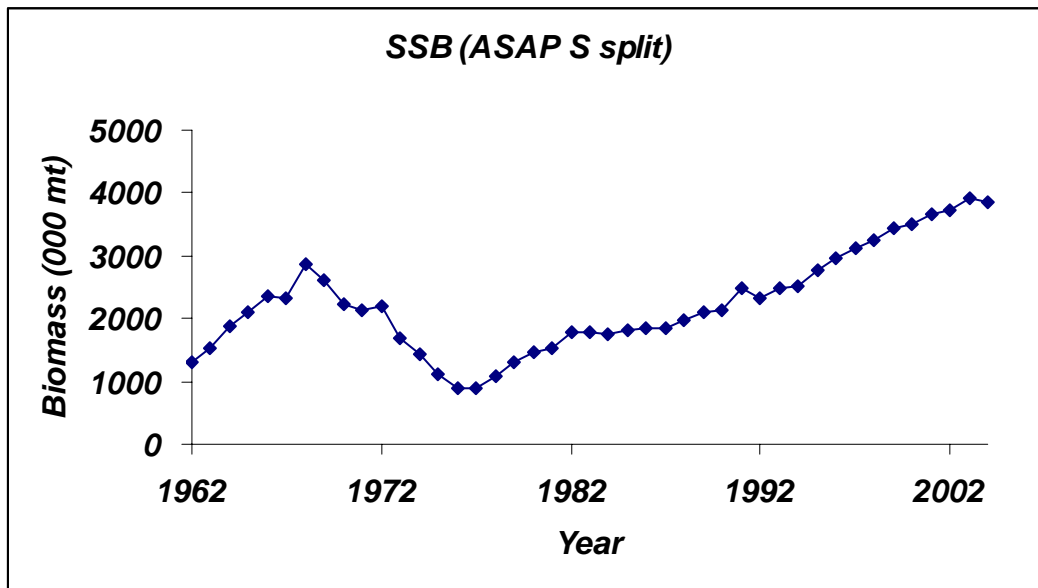


Figure 13 (APPENDIX B1). Spawning stock biomass for an ASAP trial run with the spring survey split into pre 1985 (1968-1984) and post 1985 (1985-2004) series.

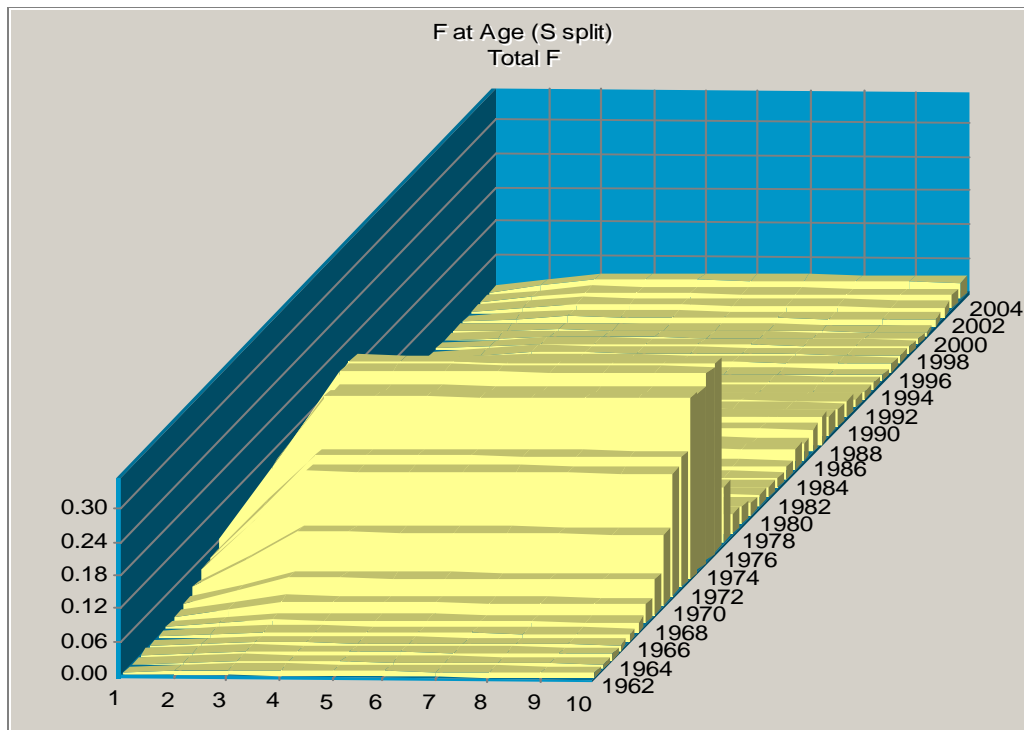


Figure 14 (APPENDIX B1). Fishing mortality by age and year for an ASAP trial run with the spring survey split into pre 1985 (1968-1984) and post 1985 (1985-2004) series.

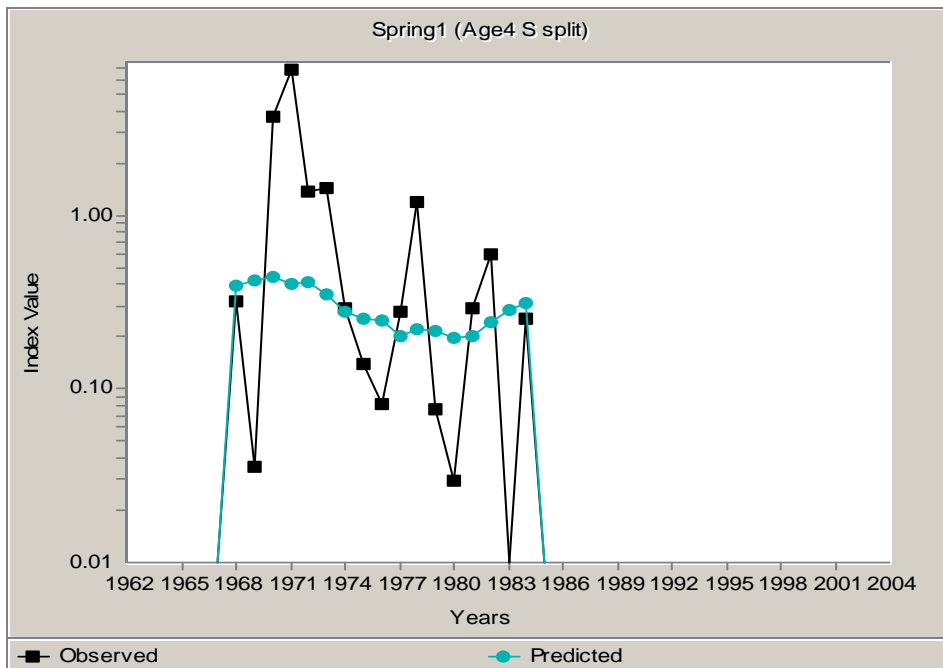


Figure 15 (APPENDIX B1). Spring survey observed vs. predicted series (1968-1984, age 4) for an ASAP trial run with the spring survey split into pre 1985 (1968-1984) and post 1985 (1985-2004) series.

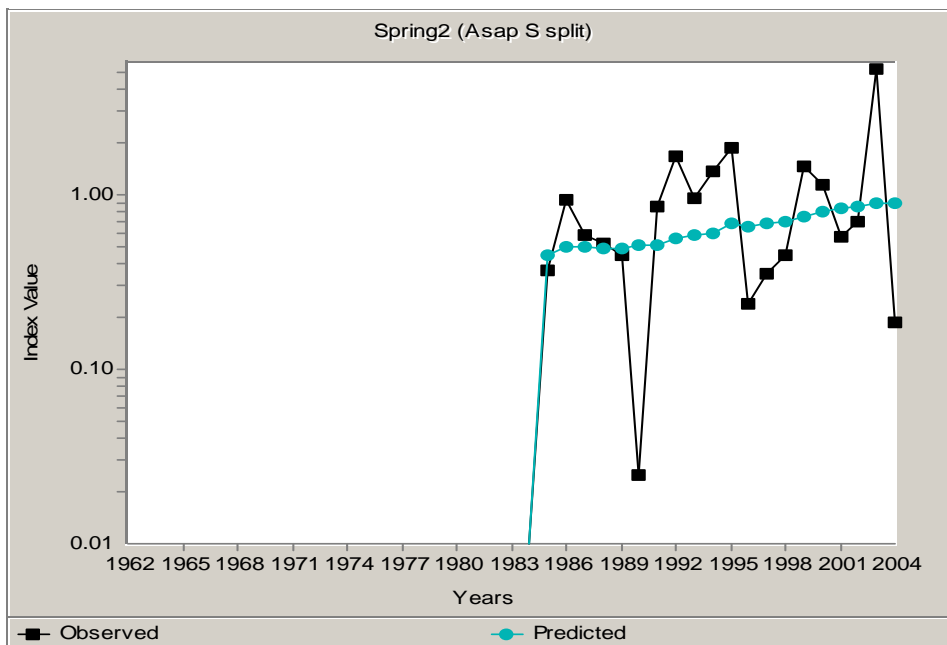


Figure 16 (APPENDIX B1). Spring survey observed vs. predicted series (1985-2004, age 4) for an ASAP trial run with the spring survey split into pre 1985 (1968-1984) and post 1985 (1985-2004) series.

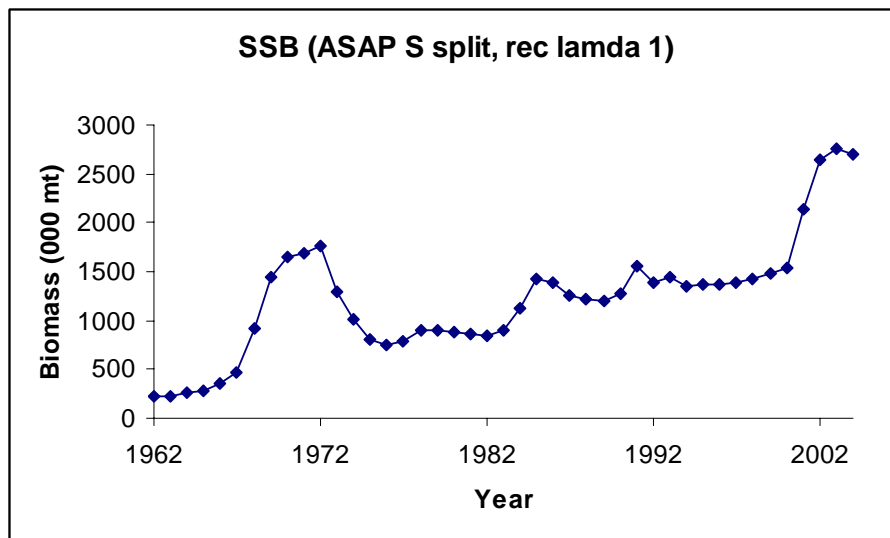


Figure 17 (APPENDIX B1). Spawning stock biomass for an ASAP trial run with the spring survey split into pre 1985 (1968-1984) and post 1985 (1985-2004) series and a B-H SR relationship with $\lambda = 1$.

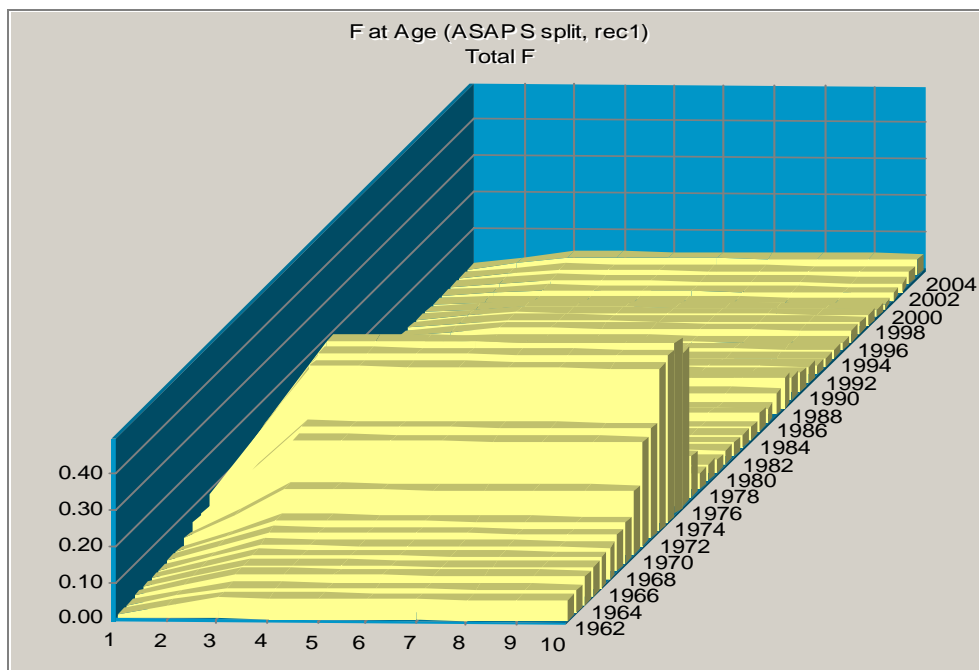


Figure 18 (APPENDIX B1). Fishing mortality for an ASAP trial run with the spring survey split into pre 1985 (1968-1984) and post 1985 (1985-2004) series and a B-H SR relationship with $\lambda = 1$.

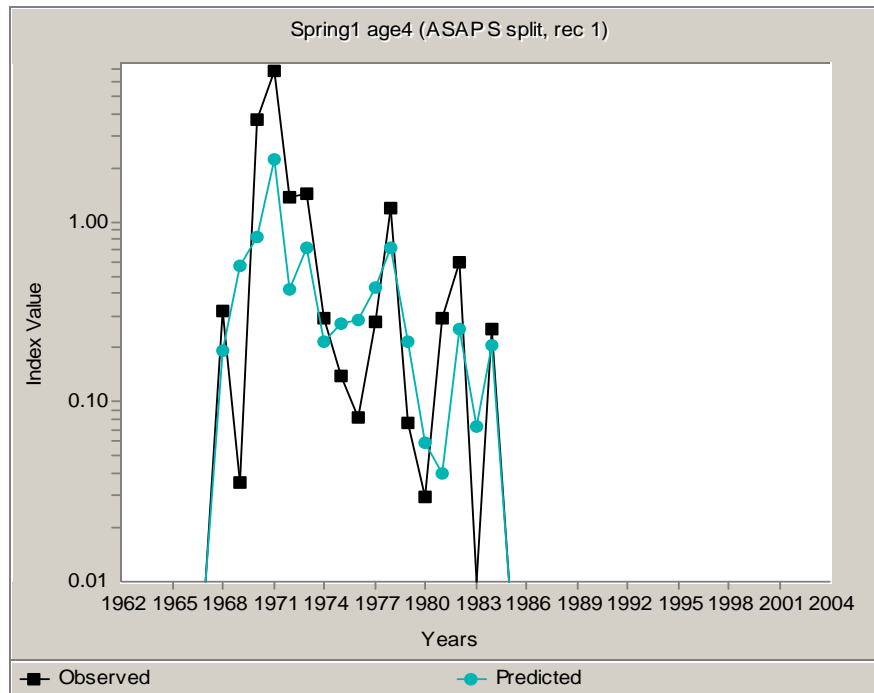


Figure 19 (APPENDIX B1). Spring survey observed vs. predicted series (1968-1984, age 4) for an ASAP trial run with the spring survey split into pre 1985 (1968-1984) and post 1985 (1985-2004) series and a B-H SR relationship with $\lambda = 1$.

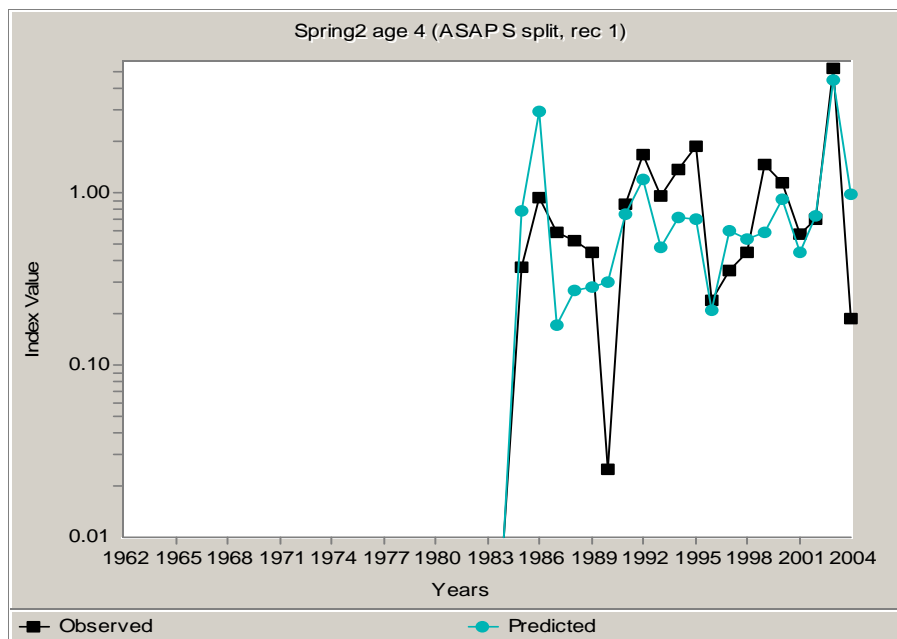


Figure 20 (APPENDIX B1). Spring survey observed vs. predicted series (1985-2004, age 4) for an ASAP trial run with the spring survey split into pre 1985 (1968-1984) and post 1985 (1985-2004) series and a B-H SR relationship with $\lambda = 1$.

Appendix B2. Sensitivity Runs for Atlantic mackerel stock assessment.

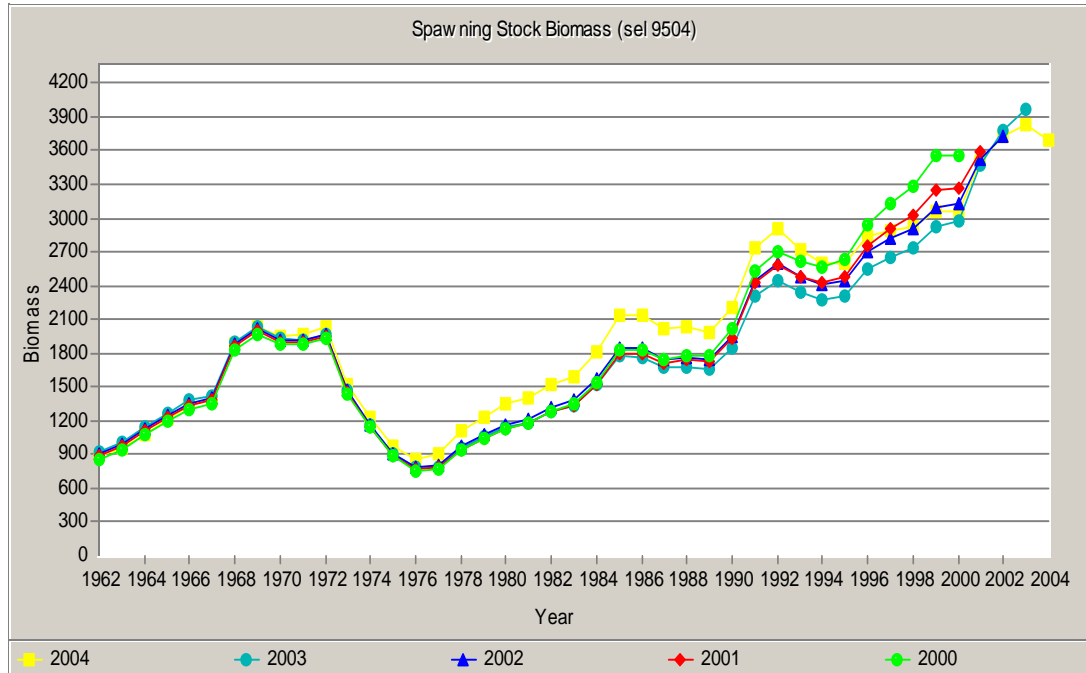


Figure 1 (APPENDIX B2). Retrospective pattern for SSB for the ASAP model with the spring survey split in 1985, B-H SR model ($\lambda = 1$), ages aggregated to 7+, and estimated fishery selectivity during 1995-2004.

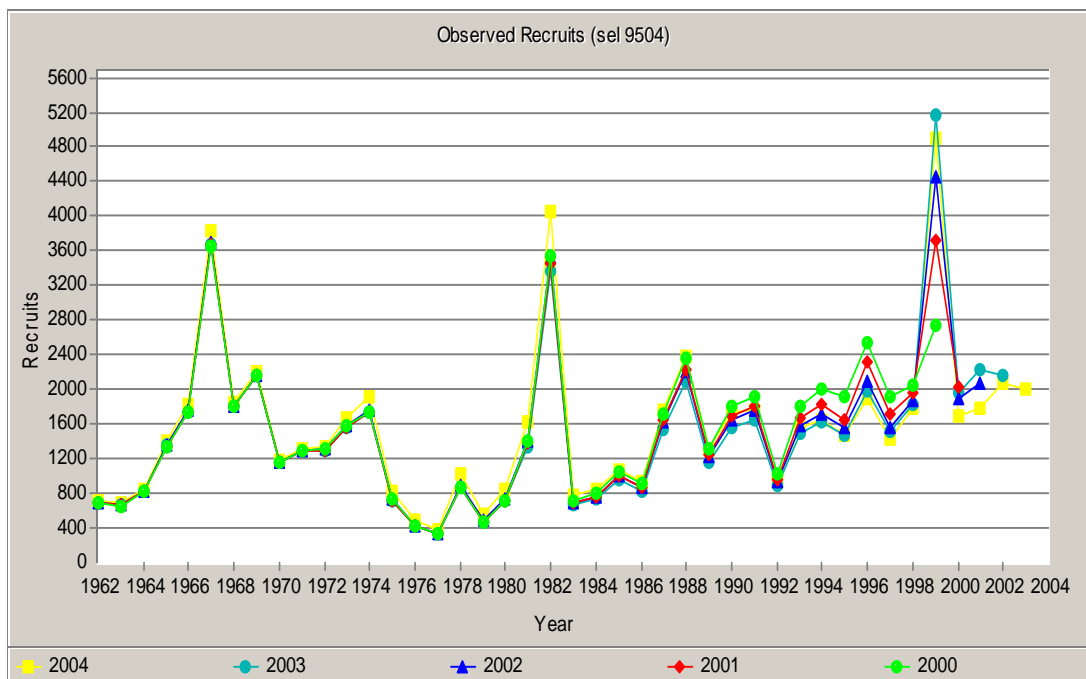


Figure 2 (APPENDIX B2). Retrospective pattern for recruitment for the ASAP model with the spring survey split in 1985, B-H SR model ($\lambda = 1$), ages aggregated to 7+, and estimated fishery selectivity during 1995-2004.

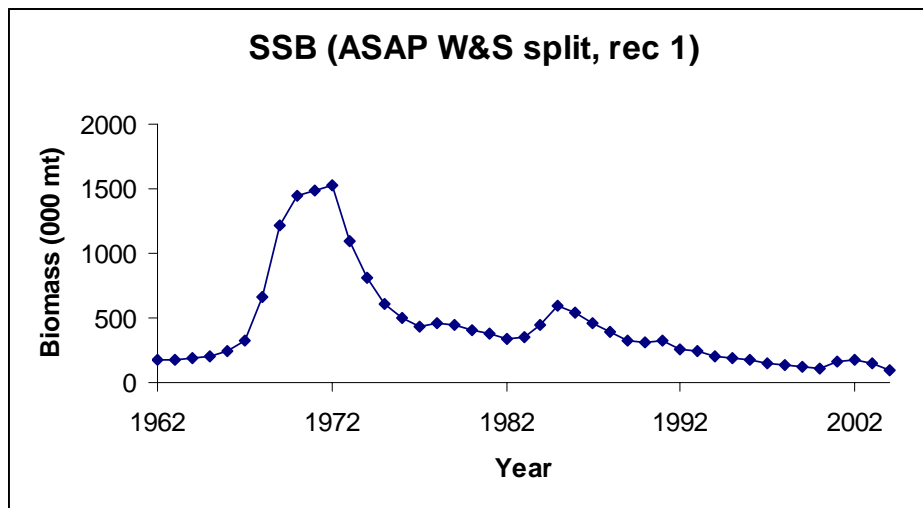


Figure 3 (APPENDIX B2). Sensitivity run to assess the effect of adding the NEFSC winter survey to the ASAP model, impact on spawning stock biomass.

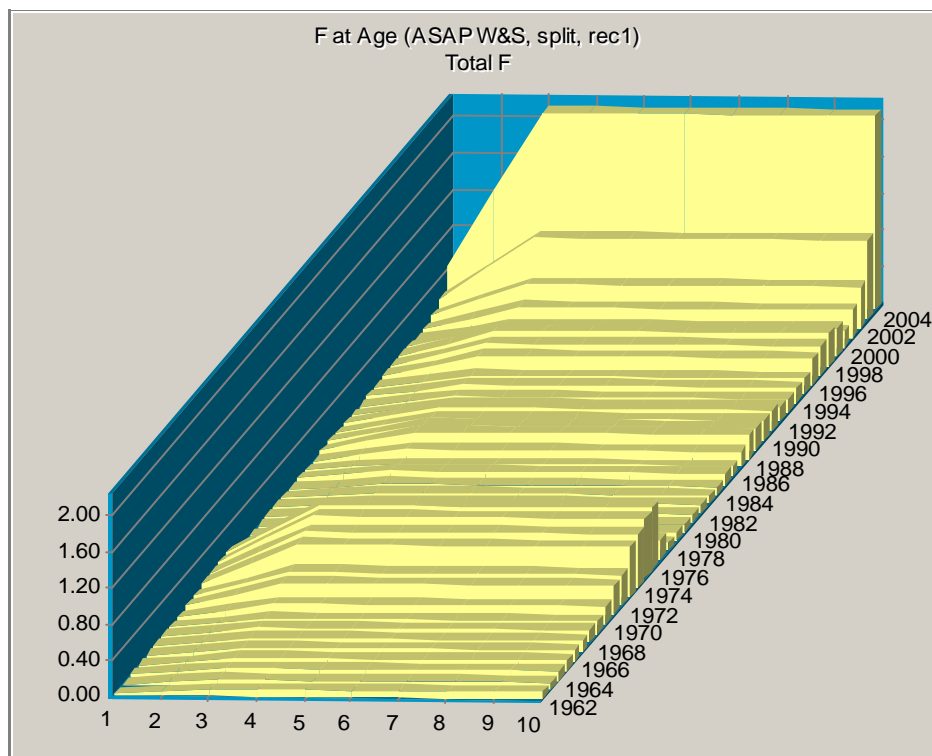


Figure 4 (APPENDIX B2). Sensitivity run to assess the effect of adding the NEFSC winter survey to the ASAP model, impact on fishing mortality.

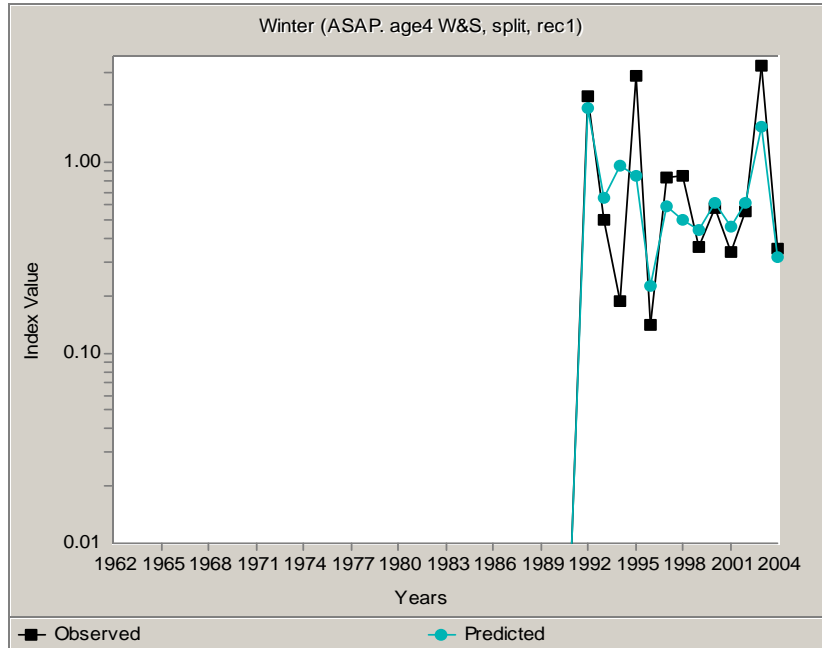


Figure 5 (APPENDIX B2). Sensitivity run to assess the effect of adding the NEFSC winter survey to the ASAP model, impact on winter survey observed vs. predicted series.

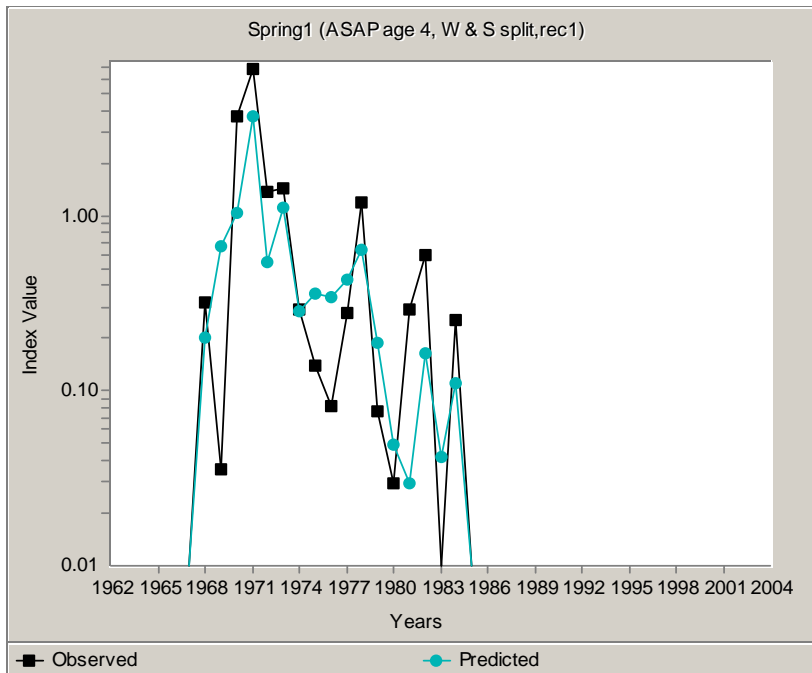


Figure 6 (APPENDIX B2). Sensitivity run to assess the effect of adding the NEFSC winter survey to the ASAP model, impact on spring1 survey observed vs. predicted series.

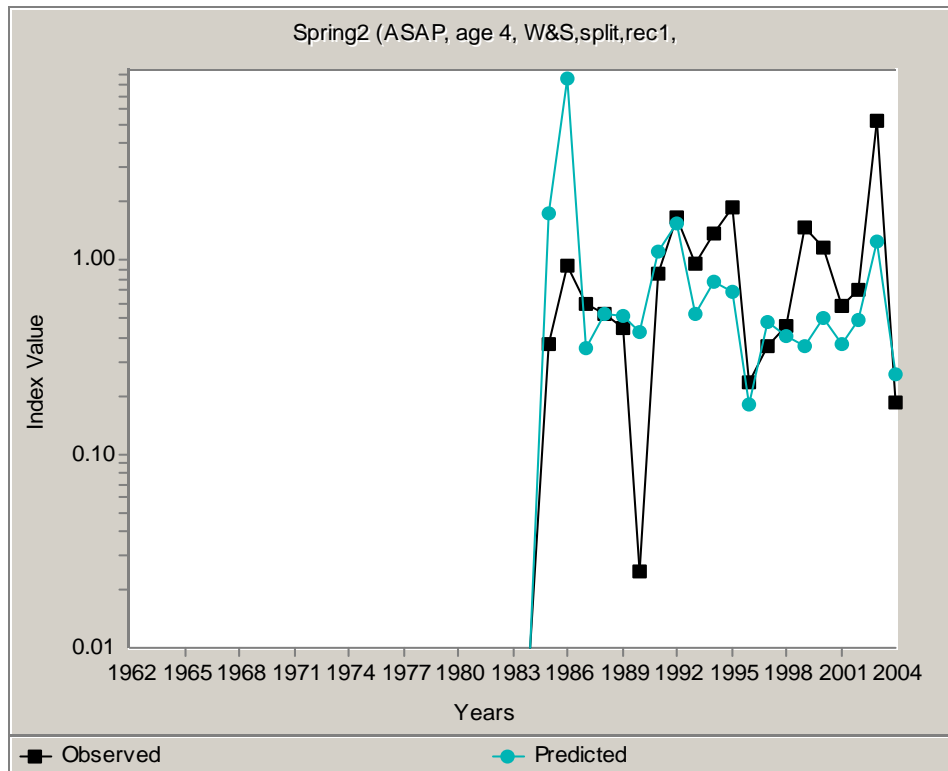


Figure 7 (APPENDIX B2). Sensitivity run to assess the effect of adding the NEFSC winter survey to the ASAP model, impact on spring2 survey observed vs. predicted series.

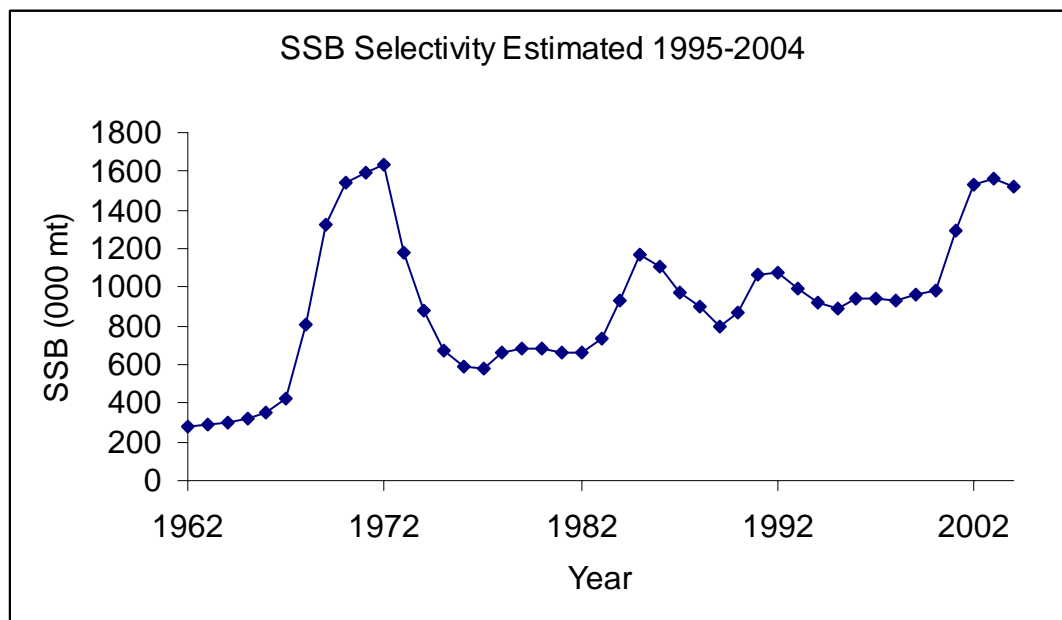


Figure 8 (APPENDIX B2). Results for SSB from a sensitivity run to assess the effect of estimating fishery selectivity during 1962-1994 and 1995-2004 in the ASAP model.

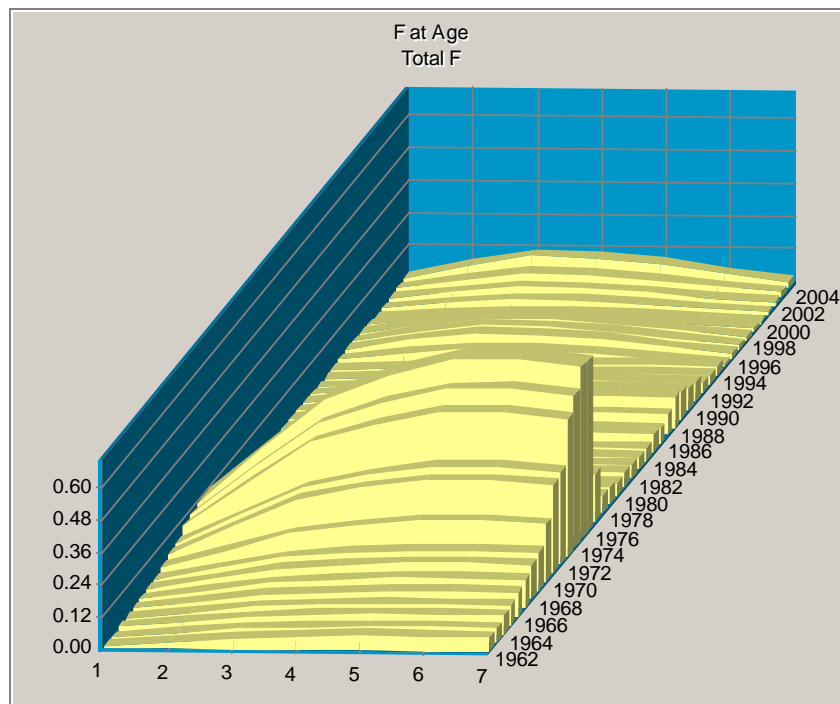


Figure 9 (APPENDIX B2). Results for fishing mortality from a sensitivity run to assess the effect of estimating fishery selectivity during 1962-1994 and 1995-2004 in the ASAP model.

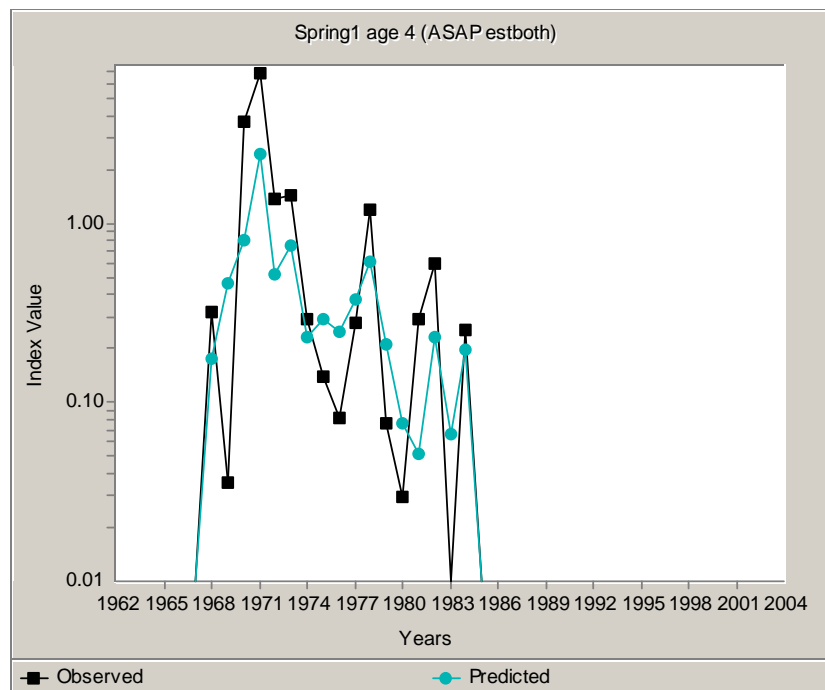


Figure 10 (APPENDIX B2). Sensitivity run to assess the effect of estimating fishery selectivity during 1962-1994 and 1995-2004 in the ASAP model on spring1 survey observed vs. predicted series.

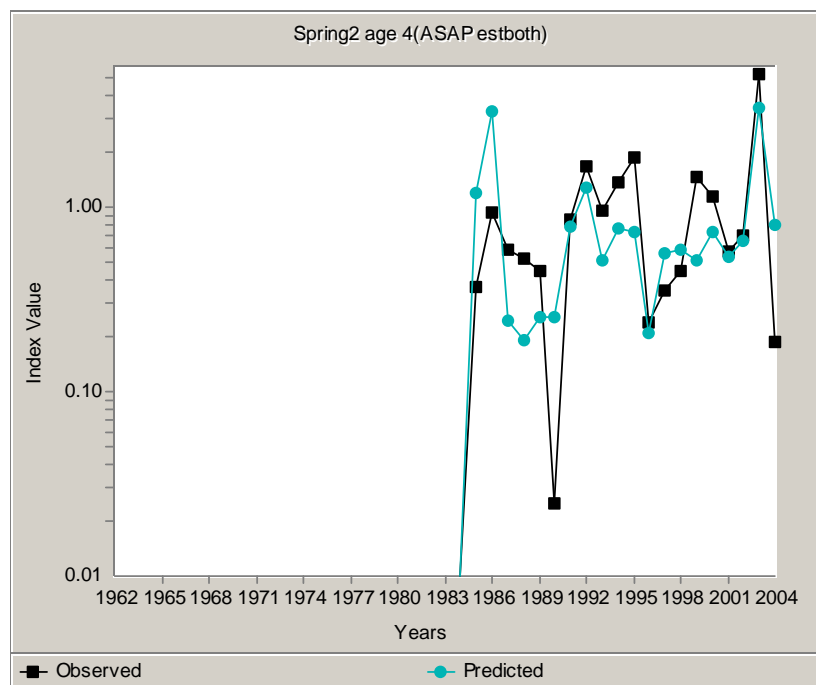


Figure 11 (APPENDIX B2). Sensitivity run to assess the effect of estimating fishery selectivity during 1962-1994 and 1995-2004 in the ASAP model on spring2 survey observed vs. predicted series.

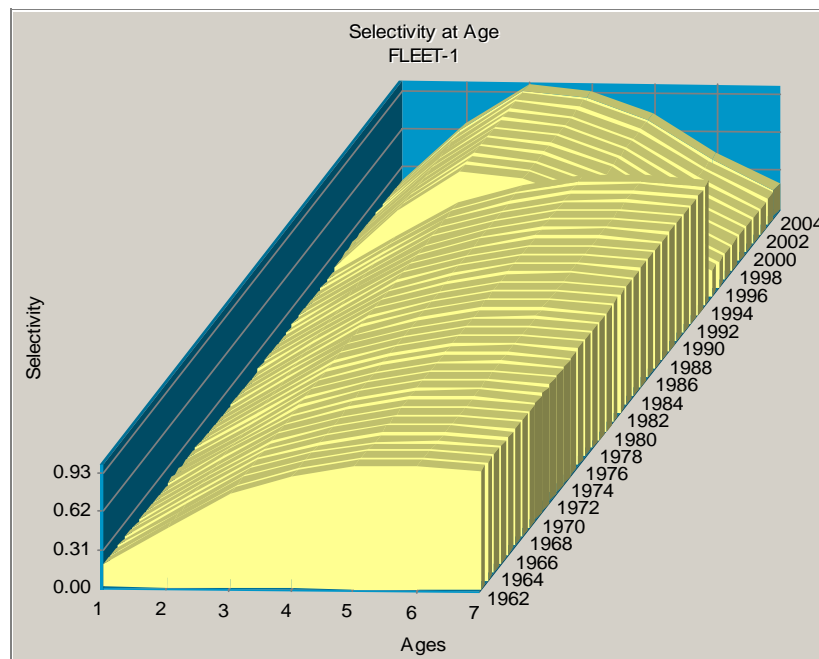


Figure 12 (APPENDIX B2). Sensitivity run to assess the effect of estimating fishery selectivity during 1962-1994 and 1995-2004 in the ASAP model on fishery selectivity.

APPENDIX B3: Rapporteur's Report from Mackerel Working Group Meeting

Concerns were raised regarding the lack of correspondence between the total landings from VTR and weighout data for 2004. Although some Atlantic mackerel may be going to bait markets without passing through dealers, industry representatives think 85-90% of landings pass through dealers, accounting for the vast bulk of landings. In Canada it is known that there is underreporting of catch going to the bait market, but they cannot quantify the magnitude, although it is not expected to be a major portion of the catch. There are no discard estimates but these catches are thought to be minor based on the gear required to catch mackerel in most years. However, as large year classes enter the fishery discarding of small fish may be an issue. The Working Group agreed that current catch estimates are reasonable.

The Working Group noted that although commercial landings increased in 2004 the number of length and age samples collected decreased. The 2004 sampling was inadequate and sampling should increase in future years to ensure the estimated catch at age is representative of the actual landings.

The relative lack of old fish in both the commercial catch and the surveys caused concern. Several possible explanations were discussed. The most likely explanations for the commercial catch was either a shift in location of the fishery to more inshore waters where older fish are less available, a shift in the location of fish due to environmental conditions, or insufficient sampling of the catch to detect the old fish amongst the more numerous younger fish. It was noted that the surveys have never caught large numbers of old mackerel but it could not be easily explained why the old fish are not currently seen by the survey if they are present in the area. The alternative explanation of a high fishing mortality rate does not agree with the recent low catches compared to historical catches. The Canadian fishery is targeting the large 1999 year class, which could explain the lack of old fish in that portion of the landings.

Retransformation of the spring index was discussed in detail. The technical procedure was described but an apparent inconsistency between the regular scale and retransformed data caused concern, specifically the change in direction from 2003 to 2004 between the regular and retransformed plots. It was explained that single large tows can lead to this apparent inconsistency. Since the retransformed data is then split into age groups, and the age samples from the early part of the time series are not available electronically, it is currently not possible to compute untransformed indices for the entire time series.

The Canadians have observed large changes in migration paths, timing of arrival and departure, distribution, etc. in recent years. This has made Canadian surveys difficult to use because their surveys are not measuring changes in abundance but rather changes in availability. They are continuing to explore development of indices, but the indices are not ready yet.

The Working Group agreed that since it is not possible currently to quantify the impact of consumption by predators on the natural mortality rate, the use of constant M in modeling is justified.

The Working Group agreed that the VPA models did not provide reasonable estimates for this stock and so was not used as a tool for classifying current stock status. The added structure in the

ASAP model allowed development of a Base Case analysis and a number of sensitivity runs to evaluate current stock status. The Base Case ASAP run has good fits to the indices and catch at age data, but exhibits a retrospective pattern. The Working Group concluded that it was preferable to keep this model even though it has a retrospective pattern because the approach that reduced the retrospective pattern, allowing a dome in recent years for the commercial fishery, could not be sufficiently justified. The Working Group agreed that without strong evidence for a domed pattern in recent years, the default of an asymptotic pattern for all years was most appropriate for this stock. The uncertainty in the recent SSB estimates was relatively high and encompassed most sensitivity runs.

C. ASSESSMENT OF NORTHERN SHORTFIN SQUID ON THE EASTERN USA SHELF DURING 2003 and 2004

A Report of the
SARC 42 Assessment Working Group
National Marine Fisheries Service
Northeast Fisheries Science Center
Woods Hole, MA 02543

EXECUTIVE SUMMARY

The northern shortfin squid, *Illex illecebrosus*, inhabits the continental shelf and slope waters of the Northwest Atlantic Ocean between Iceland and the east coast of Florida and constitutes a unit stock throughout its range. The species is highly migratory, growth is rapid and the lifespan is short, up to 215 days for individuals inhabiting the USA shelf. *I. illecebrosus* is semelparous and females spawn and die within several days of mating. Thus, natural mortality increases with age for the age range where spawning occurs. Fishing mortality and spawning mortality occur simultaneously. Stock structure is complicated by the overlap of seasonal cohorts. Age data indicate that spawning occurs throughout the year and that the first several months of the US fishery are supported by the winter cohort. The onset and duration of the fisheries occur in relation to annual migration patterns on and off the continental shelf which appear to be highly influenced by environmental conditions. On the USA shelf, a bottom trawl fishery generally occurs during June through October. Since its inception in 1987, the domestic fishery has taken a majority of the total annual landings. In recent years, there has been no fishery on the Scotian Shelf and landings from the Newfoundland jig fishery have been very low. There are no stock-wide research surveys and it is unknown whether NEFSC research bottom trawl surveys track *Illex* abundance or its availability on the shelf because these surveys cover only a portion of the *Illex* habitat and they occur during migration periods.

The northern stock component, extending from Newfoundland to the Scotian Shelf, is assessed annually and managed by the Northwest Atlantic Fisheries Organization (NAFO) based on a total allowable catch (TAC). The southern stock component, extending from the Gulf of Maine to the east coast of Florida, is managed by the Mid-Atlantic Fisheries Management Council (MAFMC) based on an annual TAC. According to the regulations, closure of the directed fishery occurs when 95% of the quota has been landed. At that time, a trip limit of 4.5 mt (10,000 lbs) takes effect. The stock was last assessed in 2003, at SAW 37, and updated fishery and survey data for 1999-2002. At SAW 37, it was not possible to evaluate stock status because there were no reliable estimates of stock biomass or fishing mortality rates. However, based on qualitative information, it was determined that overfishing was not likely to have occurred during 1999-2002. Stock status with respect to biomass was unknown.

The current assessment focuses on the southern stock component, particularly during 2003 and 2004, but survey indices and landings from the northern stock component are also presented. This is a data-poor stock, and because there are no reliable research survey indices for *Illex* inhabiting the U.S. Shelf, the assessment relies on fisheries data, in particular, catch per unit

effort (CPUE) indices and biological data collected during prior cooperative research projects. Due to its short lifespan and the short fishing season, *Illex* was assessed using an in-season (weekly) model. Estimates of natural mortality were included in the in-season model and in a weekly per-recruit model. Although the Working Groups felt the model formulations were sound, it was decided that the use of the results from the three models was premature, mainly due to a lack of seasonal age, growth and maturity data which greatly affect the model results. Due to the lack of adequate data regarding fishing mortality rates and absolute biomass, stock status could not be determined for 2003 or 2004.

TERMS OF REFERENCE

The following Terms of Reference were addressed and are summarized below:

- 1.) *Characterize the commercial and recreational catch including landings and discards.*

There is no recreational fishery for *Illex*. Landings and discards from the USA fishery were updated for 2003 and 2004. Landings from the fisheries involving the northern stock component (Scotian Shelf and Newfoundland) were also updated for 2003 and 2004. Refer to Section 3.0.

- 2.) *Estimate fishing mortality, spawning stock biomass, and total stock biomass for the current year and characterize the uncertainty of those estimates.*

A revised version of the SARC 37 in-season assessment model was run using data for 2003 and 2004. However, the model estimates of fishing mortality and stock size were not reliable because new data on seasonal growth rates and maturity are required for the model. Refer to Section 7.0.

- 3.) *Evaluate and either update or re-estimate biological reference points as appropriate.*

A revised version of the SARC 37 maturation-natural mortality model was presented but the results were not considered reliable because new data on seasonal growth rates and maturity are required for the model. Because the preliminary natural mortality estimates are a data input to the per-recruit models that were used to estimate biological reference points, the reference point estimates from the per-recruit models were also considered preliminary. In addition, seasonal changes in growth rates are likely for this species and this will affect the reference point estimates. Therefore, seasonal growth rate data are required to test the sensitivity of the per-recruit models to growth rates. Refer to Section 6.0.

- 4.) *Where appropriate, estimate a TAC and/or TAL based on stock status and target fishing mortality rate for the year following the terminal assessment year.*

- 5.) *If possible,*

- a. *provide short term projections (2-3 years) of stock status under various TAC/F strategies and*
- b. *evaluate current and projected stock status against existing rebuilding or recovery schedules, as appropriate.*

As *Illex* is a sub-annual species, assessments should be based on data from the current year. However, stock assessments are prepared for the previous year because data for the current year are unavailable at the time of the assessment and/or the current year's fishery is ongoing at the time of the SARC. Consideration of the timing of the *Illex* assessment and the collection of in-season assessment data are needed to remedy these issues.

6.) *Review, evaluate and report on the status of the SARC/Working Group Research Recommendations offered in previous SARC-reviewed assessments.*

The accomplishment of many of the previous SARC research recommendations, as a result of external grant funds obtained by the lead assessment scientist and cooperative research projects, has resulted in an increased understanding of the complex life history of this species and has allowed the development and testing of new models which appear promising. This information has been documented in several journal and report publications. Refer to Section 9.0 for the status of the SARC 37 research recommendations.

1.0 INTRODUCTION

An initial review of the *Illex illecebrosus* assessment was conducted on October 3, 2005 at a meeting of the Invertebrate Working Group held at the Northeast Fisheries Science Center in Woods Hole, Massachusetts. Lynne Purchase, a squid assessment scientist from the Renewable Resources Assessment Group (RRAG), at Imperial College in London, attended the meeting as an external reviewer. Ms. Purchase's comments are presented in Appendix C1. The assessment was revised according to the recommendations made at the October 3 meeting and was reviewed again at a second Working Group meeting held during October 24-28 in Woods Hole, MA. The comments from second Working Group meeting are included in Appendix C2. The follows persons attended the second meeting:

Name	Organization
Jay Burnett	NMFS/NEFSC
Ralph Mayo	NMFS/NEFSC
Larry Jacobsen	NMFS/NEFSC
Chris Legault	NMFS/NEFSC
Susan Wigley	NMFS/NEFSC
Laurel Col	NMFS/NEFSC
Jim Weinberg	NMFS/NEFSC
Mark Terceiro	NMFS/NEFSC
Azure Westwood	NMFS/NEFSC
Dan Farnham	Industry Advisor
Kathy Lang	NMFS/NEFSC
Paul Rago	NMFS/NEFSC
Bill Overholtz	NMFS/NEFSC
Vidar Wespestad	Industry Consultant
Jim Ruhle	Industry Advisor
Dvora Hart	NMFS/NEFSC
Mauricio Ortiz	NMFS/SEFSC

Dana Hanselman	NMFS/AFSC
Eric Powell	Rutgers University
Francois Gregoire	DFO, Canada
Lisa Hendrickson	NMFS/NEFSC
Rich Seagraves	MAFMC
Marybeth Tooley	ECPH
Paul Nitschke	NMFS/NEFSC
Steve Cadrin	NMFS/NEFSC/SMAST
Mary Radlinski	SMAST

The *Illex illecebrosus* stock was last assessed in 2003 at the 37th Stock Assessment Workshop (SAW) (NEFSC 2003). The assessment included updates of fisheries and research survey data for 1999 through 2002. An in-season (weekly) assessment model that incorporated recruitment, landings and effort data, mean body weights from the fishery, and natural mortality rates computed from a maturation-natural mortality model were used to estimate initial stock size and fishing mortality rates in the U.S. fishing area during 1999 but the model was considered preliminary because additional testing was required (NEFSC 2003). The SARC 37 assessment also included a weekly yield-per-recruit (YPR) and egg-per-recruit (EPR) analysis which was also considered premature. With respect to stock status, SARC 37 concluded that it was not possible to evaluate the current stock status because there are no reliable estimates of absolute stock biomass or fishing mortality rate.

The current assessment pertains to the southern stock component (US EEZ, from the Gulf of Maine to Cape Hatteras, NC), but also summarizes landings and research survey data from the northern stock component (Newfoundland and the Scotian Shelf). Fisheries data and research survey biomass and abundance indices were updated to include 2003 and 2004. *Illex illecebrosus* is a semelparous species and an age-based maturation-natural mortality model that estimates spawning mortality rates was presented during the last assessment. The model has been reformulated, changing from a discrete time step to a continuous process. Output from the reformulated model, including the probability of spawning at age and spawning mortality rate estimates, are incorporated in yield-per-recruit and egg-per-recruit analyses along with fishery selectivity estimates and catch mean weights, during 1999-2002, to estimate biological reference points. Results from the reformulated maturation-natural mortality model and the per-recruit models are taken from a journal publication (Hendrickson and Hart 2006) prepared by the *Illex* assessment scientists. The in-season stock assessment model that was considered preliminary during the last assessment was further developed and tested using simulation analyses. Simulation analysis results are presented herein.

2.0 BACKGROUND

The northern shortfin squid, *Illex illecebrosus*, inhabits the continental shelf and slope waters of the Northwest Atlantic Ocean between Iceland and the east coast of Florida and is assumed to constitute a unit stock throughout its range (Dawe and Hendrickson 1998). The northern stock component, extending from Newfoundland to the Scotian Shelf, is assessed annually and managed by the Northwest Atlantic Fisheries Organization (NAFO) based on a total allowable catch (TAC). The southern stock component, extending from the Gulf of Maine to the east coast

of Florida, is managed by the Mid-Atlantic Fisheries Management Council (MAFMC) based on an annual TAC.

The life history and habitat requirements of *I. illecebrosus* are summarized in Hendrickson and Holmes (2004). The northern shortfin squid is a highly-migratory ommastrephid that lives for up to one year (Dawe et al. 1985; Dawe and Beck 1997; O'Dor and Dawe 1998; Hendrickson 2004). Temporal and spatial distribution patterns are highly variable at the northern limit of this species' range (Newfoundland) and are associated with environmental factors (Dawe et al. 1998). Recruitment dynamics are complex and have not been fully elucidated for the U.S. EEZ component of the stock, so reliable predictions of annual recruitment levels are not currently possible. Stock structure is complex and, in Newfoundland waters, is complicated by overlapping seasonal cohorts that migrate through the fishing grounds (Dawe and Beck 1997). Mean size at maturity varies between northern and southern geographic regions in some years (Coelho and O'Dor 1993). However, it is not known whether these differences are due to inherent population structure. O'Dor and Coelho (1993) speculated that changes in the seasonal spawning patterns could have played a role in the collapse of the Canadian fishery during the early 1980's.

The *Illex* stock is fished on the continental shelf from Newfoundland, Canada to Cape Hatteras, North Carolina. However, there are no stock-wide indices of relative abundance or biomass. The NEFSC bottom trawl surveys do not cover the entire habitat range of the species and it is unknown whether the survey indices measure relative abundance or availability to the survey gear. In addition, CPUE data for the US fishery is of coarse temporal and spatial resolution and age and growth information for the U.S. stock component is limited to data from a single pre-fishery survey (Hendrickson 2004). As a result, research recommendations in previous assessments have emphasized the need for improved stock assessment data, particularly given the short lifespan and short fishing season (4-5 months on average for the US fishery).

Since 1997, the NEFSC has conducted multiple cooperative research projects with the *Illex* fishing industry that have increased our knowledge about the age, growth and life history of *Illex* in US waters (Hendrickson 2004) and that have improved the spatial and temporal resolution of fisheries catch, effort and biological data in real-time via electronic logbook reporting (Hendrickson et al. 2003). The products of these research projects have been used extensively in new assessment models that take into account the semelparous life history of *I. illecebrosus*.

Commercial fisheries for *I. illecebrosus* occur from Newfoundland to Cape Hatteras, North Carolina. The bottom trawl fishery operating within the U.S. EEZ (Northwest Atlantic Fisheries Organization Subareas 5 and 6) is managed by the Mid-Atlantic Fishery Management Council (MAFMC) and fisheries operating within Northwest Atlantic Fisheries Organization (NAFO) Subareas 2, 3 and 4 are managed by NAFO (Fig. C1). During 1980-1998, the annual total allowable catch (TAC) established by NAFO for Subareas 2-4 was 150,000 mt (NAFO 1995). The NAFO TAC was reduced to 75,000 mt in 1999 (NAFO 2000) and has been 34,000 mt since 2000 (Hendrickson et al. 2005). Annual levels of allowable biological catch (ABC) and domestic annual harvest (DAH) in the U.S. EEZ are determined in accordance with the Atlantic Mackerel, Squid and Butterfish Fishery Management Plan (SMB FMP) and are based on the best available information about the current status of the stock. During 1991-1995, the optimum yield (OY), ABC and DAH were 30,000 mt (MAFMC 1994). The DAH was reduced to 21,000 mt in 1996 (MAFMC 1995a) and 19,000 mt during the 1997-1999 fishing seasons (MAFMC 1996a; 1997a;

1998a). The DAH has been 24,000 mt since 2000 and was set at 24,000 for 2006 (MAFMC 2000; 2001; 2002).

Amendment 5 of the SMB FMP was enacted (MAFMC 1995b; 1996b) in recognition that the domestic resource was approaching full utilization and that expansion of the U.S. fleet might lead to overcapitalization. Amendment 5 established a permit moratorium to limit entry into the directed fishery, required mandatory logbook and dealer reporting as of January 1, 1997, and established a 5,000-pound trip limit for incidental catches of *Illex* by non-moratorium vessels. Amendment 6 (MAFMC 1996c) provided a mechanism for in-season closures of the *Illex* fishery, and established an overfishing definition of $F_{20\%}$ and procedures for the specification of annual quotas based on $F_{50\%}$. Amendment 7 (MAFMC 1998b) was enacted to achieve consistency between FMP's with regards to Limited Access Federal permits. Based on the requirements of the Sustainable Fisheries Act (SFA), Amendment 8 (MAFMC 1998c) established MSY-based biological reference points. Threshold and target fishing mortality rates were specified as F_{MSY} and 75% of F_{MSY} , respectively. In addition, a biomass target and minimum biomass threshold were specified as B_{MSY} and 50% of B_{MSY} , respectively. Amendment 8 also defined the essential habitat of *Illex* in the U.S. EEZ and established a framework adjustment process for specific management measures. Amendment 9 is still in draft form, and with respect to *Illex*, could extend the moratorium on entry to the commercial fishery, allow for specification of management measures covering multiple years, require electronic daily reporting, modify the exemption from the *Loligo* minimum mesh size requirement for vessels in the *Illex* fishery, implement closures to reduce gear impact on habitat, and modify the *Loligo* possession limit by *Illex* fishery vessels during *Loligo* fishery closures..

3.0 LANDINGS AND DISCARDS

Landings

A bottom trawl fishery for *I. illecebrosus* occurs on the USA shelf (NAFO Subareas 5+6) and an artisanal jig fishery occurs in inshore Newfoundland waters (NAFO Subarea 3). Historically, a bottom trawl fishery also occurred on the Scotian Shelf in NAFO Subarea 4 (Hendrickson et al. 2005). The timing and duration of the fisheries are determined primarily by the migration of the species through the fishing grounds on the continental shelf. The inshore migration into Subarea 3 generally occurs during July, approximately three months later than it occurs on the continental shelf in Subareas 4, 5 and 6. This delay in the arrival of squid on the fishing grounds is presumably a result of the position of the Gulf Stream, the hypothesized transport mechanism for paralarvae hatched during the winter (Trites 1983), being located further from shore in this northern region. An unusually early inshore arrival of squid occurred in Subarea 3 during June of 1987, when 78% of the landings for that year were taken. *Illex* remains on the shelf longer in Subarea 3 so the fishing season often extends into November after landings reach a peak in September (NEFSC 1999). Since 1992, the U.S. fishery and the Subarea 4 fishery have generally occurred during June through October with a peak in July (NEFSC 1999). Historically, foreign trawlers involved in the silver hake and argentine fishery in Subarea 4 also targeted *Illex* if it became available before the July closure of the silver hake fishing season (Mark Showell, pers. comm. 1999). However, the mixed fishery for silver hake, argentine and *Illex* has not operated in Subarea 4 since 2000 (Hendrickson et al. 2004).

Illex landings (mt) during 1963-2005 are presented for the southern stock component inhabiting the US EEZ (NAFO Subareas 5+6) as well as the northern stock component (NAFO Subareas 3+4, Table C1, Fig. C2). US EEZ landings are partitioned into foreign and domestic components and the total allowable catches (TACs) for Subareas 3+4 and Subareas 5+6 are also presented. During 1963-1976, U.S. EEZ landings of squid by distant water fleets (foreign landings) were not consistently reported by species. In addition, domestic landings of squid were not recorded by species in the commercial fisheries dealer database until 1979. As a result, U.S. EEZ landings during 1963-1978 were derived from prorations based on the temporal and spatial landings patterns of *Illex illecebrosus* and *Loligo pealeii*, by country, from fisheries observer data (Lange and Sissenwine 1980). U.S. EEZ landings for 1979-2005 were obtained from the Weighout Database, which consists of fish purchases by dealers, and also include landings from joint ventures that occurred during 1982-1990 between U.S. and foreign fishing vessels. Dealer reporting of *Illex* purchases has been mandatory since January 1, 1997. Since April of 2004, dealers have been required to enter their fish purchases electronically in the Weighout Database these data are considered preliminary. Landings from NAFO Subareas 3+4, during 1963-2004, were obtained from Hendrickson et al. (2005).

Total *Illex* landings have varied considerably since 1963 and have consisted of three distinct levels of magnitude (Fig. C2A). A period of high landings, which occurred during 1976-1981 when distant water fleets were active in all NAFO fishing areas, was bracketed by periods of substantially lower landings. During 1963-1967, total landings were low, averaging 7,354 mt, and were primarily from the Subarea 3 inshore jig fishery. During 1968-1974, total landings averaged 13,470 mt and were predominately from distant water fleets that had begun fishing in Subareas 5+6. However, this trend was reversed during 1976-1981, when landings were predominately from Subareas 3+4. During this time, total landings averaged 100,300 mt, and in 1979, reached the highest level on record (179,333 mt). Thereafter, landings from Subareas 3+4 declined rapidly from 162,092 mt in 1979 to 426 mt in 1983. However, landings from Subareas 5+6 remained stable and did not exceed 25,000 mt, in part, due to effort limitations placed on the distant water fleets. Since its inception in 1987, landings from the domestic bottom trawl fishery have comprised a majority of the total landings. The exception occurred in 1997, when landings from Subareas 3+4 (15,485 mt) exceeded U.S. EEZ landings (13,629 mt) and were at their highest level since 1982. Landings from Subareas 3+4 declined to 57 mt in 2001, and then gradually increased to 2,034 mt in 2004. Since 2000, landings from Subareas 3+4 have primarily been from the Newfoundland jig fishery (Hendrickson et al. 2004).

U.S. EEZ landings have been characterized by two distinct periods (Fig. C2B). During 1968-1982, U.S. EEZ landings were predominately taken by distant water fleets, and in 1976, reached a peak of 24,936 mt. U.S. EEZ landings subsequently declined to 1,958 mt in 1988 (Fig. C2B) when foreign participation in the U.S. *Illex* fishery became prohibited in order to foster development of a domestic fishery. During 1998-1994, landings from the domestic fishery increased from 1,958 mt to 18,350 mt, then reached a peak of 23,597 mt in 1998. This 1998 peak led to a closure of the fishery because the quota (19,000 mt) was reached. During 1999-2002, U.S. landings declined and reached their lowest level in 2002 (2,750 mt) since the 1987 inception of the domestic fishery. U.S. landings increased to 6,389 mt in 2003 then reached their highest level on record in 2004 (26,087 mt) which resulted in a closure of the fishery because the quota (24,000 mt) was reached. A preliminary estimate of the U.S. landings for 2005 is 11,429 mt.

A majority ($\geq 98\%$) of the annual landings from the U.S. EEZ are taken with bottom trawls (Table C2). Domestic fishing effort is greatly influenced by the global market demand for squid and is limited by onshore and at-sea freezer storage capacity as well as the availability of *Illex* to the bottom trawl fishery. The Vessel Trip Report (VTR) database and NEFSC Sea Sampling database indicate that the U.S. EEZ *Illex* fishery occurs primarily at depths between 128 and 366 m. Gear limitations prevent fishing in waters deeper than 457 m (Glenn Goodwin, pers. comm. 1999).

Since January 1, 1997, *Illex* moratorium permit holders have been required to report catch, effort and fishing location data to NMFS on Vessel Trip Reports from which the data are entered into the Vessel Trip Report (VTR) Database. Landings recorded in the Weighout Database are considered more accurate than the kept fraction of the catch reported on the VTRs because the latter represent estimates made by vessel captains. However, the fishing effort and location data required to compute landings per unit of effort (LPUE) are only recorded in the VTR Database and there is no single field that directly links trips from the WO Database with those from the VTR Database. Therefore, in order to avoid the use of prorated landings to compute weekly LPUE, weekly trends in landings were compared between the VTR and Weighout Databases to determine whether the VTR landings could be used to compute LPUE.

Trends in weekly *Illex* landings and the duration of the fishing season vary by year. During 1999-2004, trends in weekly *Illex* landings were similar for the VTR and WO Databases. During 1999-2002, the fishery began during weeks 23 or 24 and lasted for a period of 16 to 21 weeks (Fig. C3). During 2003, weekly landings varied without trend, which is characteristic of years with low fishing effort, such as 2001 and 2002 (NEFSC 2003), and the duration of the fishing season was longer than normal (23 weeks). The variability in weekly landings trends is partly attributable to the coarse temporal resolution of the WO and VTR Databases, which necessitates assigning week of the year by the date landed instead of the tow date. Tow-based data associated with real-time fisheries data reporting show less variability (NEFSC 2003; Hendrickson et al. 2003). Some of the variability in the weekly landings trends for both databases is attributable to the coarse resolution of the landings data (trip-based rather than tow-based) which requires trips to be assigned to weeks based on the date landed rather than the date caught. During the Working Group meeting, the weekly landings figure for 2004 suggested that *Illex* landings reported in the VTR Database underestimated the landings in the WO Database. This discrepancy was subsequently re-examined and Figure C3 has been revised to reflect the updated WO data for 2004, which now indicates similar trends in magnitude between weekly landings from the two databases. This data revision does not impact any other assessment computations. The WO and VTR Databases indicate that the weekly landings during 2004 were more than double the weekly landings obtained during 1999-2003. Weekly landings during 2004 show an increasing trend followed by a decreasing trend, with an inflection point at week 35. Landings increased rapidly between weeks 20 and 24, and then stabilized at about 1,600 mt per week through week 32. Thereafter, landings increased further and reached a peak of 2,730 mt in week 35. The fishery was closed after week 38 because the quota was taken, but landings declined prior to this time, between weeks 35 and 38.

Discards

Two sources of data are available for estimating *Illex* discards, data from the NEFSC Observer Program Database and the VTR Database. Although reporting of discards is required on VTRs,

reporting of *Illex* discards is inconsistent. Therefore, *Illex* discards were quantified, by month, based on data from fishing trips monitored at sea by NEFSC fishery observers.

In addition to the *Illex* fishery, which is characterized by 34.9-60.3 mm diamond mesh codends, other fisheries likely to incur *Illex* bycatch are those that utilize bottom trawls of similarly small mesh and that occur during May-November, when *Illex* is present on the U.S. continental shelf. The offshore *Loligo* fishery meets both criteria and catch data from observed trips from the NEFSC Observer Program database indicate that a majority of the *Illex* bycatch, during 1995-2004, occurred in the offshore *Loligo* fishery.

Illex discards (mt) in the *Illex* and *Loligo* fisheries were estimated, by month and year, from catch data collected during trips sampled by observers from the NEFSC Sea Sampling Program during 1995-2004. The *Illex* fishery was defined as bottom trawl trips that occurred during May-October in which *Illex* landings comprised $\geq 25\%$ of the total trip weight. The *Loligo* fishery was defined as bottom trawl trips that occurred during November-April in which *Loligo* landings comprised $\geq 25\%$ of the total trip weight. Annual estimates of *Illex* discards in the *Illex* fishery were computed by multiplying the annual discard ratio (annual *Illex* discards/annual *Illex* kept, mt) by the annual *Illex* landings. Annual estimates of *Illex* discards in the *Loligo* fishery were computed by multiplying the annual discard ratio (annual *Illex* discards/annual *Loligo* kept, mt) by the annual *Illex* landings. Annual estimates for each of the two fisheries were summed to obtain the total amount of annual discards.

The annual sampling intensity of trips observed in the *Illex* fishery was low during 1995-2003, ranging between 2 and 15 trips (Table C3). There were no *Illex* trips sampled during 2001 or 2002. During 2004, 33 trips were sampled and most trips occurred during July and August, the peak of the fishing season. Temporal discarding patterns during 1995-2004 could not be discerned because the number of trips sampled by month was not representative of the seasonal landings pattern. The amount of *Illex* discarded by the *Illex* fishery during 1995-2004 ranged between 29 mt and 344 mt per year (Table C3).

The annual sampling intensity of trips observed in the *Loligo* fishery during 1995-2003 was also low, ranging between 3 and 18 trips (Table C4). During 2004, 54 trips were sampled primarily in the offshore, winter fishery. During 1995-2004, monthly sampling coverage was inconsistent during the year-round fishing season, so monthly discarding trends could not be discerned. During January of 2001, Gear Restriction Areas (GRAs) were established to reduce scup bycatch. The Southern GRA is closed to small-mesh (< 4.5 inch codend mesh) fisheries during January through March 15. NEFSC spring survey data indicate that *Illex* migration onto the U.S. continental shelf generally begins in March, during the latter part of the closure period. However, observer data were inadequate to evaluate whether this closure area also aided in the reduction of *Illex* discarding by the *Loligo* fishery. The amount of *Illex* discarded by the *Loligo* fishery during 1995-2004 ranged between 1 mt and 1,222 mt per year and was highest in 2004.

In summary, *Illex* discard estimates are imprecise but the overall level of discards in recent years was likely low in comparison to the *Illex* landings. Most of the *Illex* discards occur in the winter offshore *Loligo* fishery (Table C5). During 1995-2004, the combined *Illex* discards from both squid fisheries ranged between 53 mt and 1,556 mt and comprised 0.5-6.0% of the annual *Illex* landings by the U.S. fishery (Table C5). *Illex* discarding in both squid fisheries was higher during 1998 and 2004, when *Illex* abundance was higher. However, a quantitative comparison of

discarding between years and months is difficult due to low sampling intensity, by month and year, in both fisheries.

Mean Body Size

For the northern stock component, trends in annual average body size are associated with annual trends in *Illex* relative abundance (Hendrickson et al. 2004). In-season changes in *Illex* body size reflect the combined effects of growth, mortality (from fishing and natural mortality), and emigration and immigration from the fishing grounds. Therefore, annual and in-season trends in *Illex* mantle length (cm) and body weight (g) were assessed for *Illex* samples obtained from the landings by squid processors and NMFS port samplers during 1994-2004. With the exception of 1996, *Illex* landed during 1999-2003 were smaller than in other years during 1994-2004. Median mantle lengths were highest during 1994 and 2004 and were lowest in 1996 (Fig. C4). Median body weight was highest during 1994 and lowest in 2001 (Fig. C4). Median mantle length and body weight during 2003 were similar to those from 2002. The median weight of squid in 2004 was the highest since 1998 and the median mantle length in 2004 was as high as in 1994. Median mantle length and body weight were significantly lower in 2001 than for most years during 1994-2004. Interannual trends in squid size are likely attributable to environmental conditions, particularly if they persist across multiple years, but size trends may also reflect fishing in different geographic areas. A review of bottom water temperature anomalies in the Mid-Atlantic Bight indicated that bottom temperatures near the shelf edge were warmer than average during large portions of the year in 1999-2002 (Jossi and Benway 2003) when *Illex* mean body size was small and catches were low.

The Lowess-smoothed trend line of a composite of the average body weights of squid landed during 1994-1998 indicated a steady increase in average size from 50-175 g during weeks 20 through 34, but the trend for smaller squid that were landed during 1999-2002 indicated an increase in body size that was more gradual, from 70 to 110g between weeks 22 through 30 (NEFSC 2003). Thereafter, average body size was generally stable. The attainment of an asymptotic average size may be partially driven by the recruitment of smaller squid, but most likely reflects the emigration of larger squid. In autumn, the density of large squid increases with depth and is highest in the deepest strata (186-366 m) during this offshore migration period (Brodziak and Hendrickson 1999). Maximum average size in the fishery during 1999-2002 occurred one month earlier, at week 30, than during 1994-1998 and was only 60% (110 g) of the 1994-1998 value (NEFSC 2003). In comparison, weekly increases in mean mantle length occurred more rapidly in 2004 than in 2003 (Fig. C5) and the weekly trends in mean body weight during 2003 resemble those from 1999-2002 while the 2004 trends are more similar to the trends observed for 1994-1998. During 2004, *Illex* mean body weights increased from 100 to 200 g between weeks 21 and 34 then declined thereafter (Fig. C6). The decline in mean body weight after week 34 may be due to recruitment, the annual offshore migration, or both factors.

4.0 RELATIVE ABUNDANCE AND BIOMASS INDICES

Research Surveys

Although there are no stock-wide indices of abundance or biomass for the *Illex* stock, several seasonal research surveys provide some information about local abundance trends on the USA

Shelf and the Scotian Shelf. The NEFSC spring bottom trawl survey occurs in March, prior to the USA fishery, but captures low densities of squid at few stations in comparison to the autumn survey because the spring survey occurs at a time when *Illex* are migrating onto the continental shelf (Hendrickson 2004). *Illex* are caught at 5-10% of the offshore stations sampled during spring surveys and at 30-80% of the offshore stations during autumn surveys (Fig. C7). The NEFSC autumn survey occurs when *Illex* are migrating off the shelf. The autumn survey indices can be considered as an index of spawner escapement because the survey occurs near the end of the fishing season. A portion of the *Illex* stock resides outside the range of the NEFSC surveys. The outer shelf and continental slope are important *Illex* habitats (Lange 1981) that are not intensively sampled during NEFSC bottom trawl surveys. In addition, the survey bottom trawl gear is not likely to sample pelagic species efficiently. Therefore, survey indices may represent the on-shelf availability of *Illex* rather than a measure of relative abundance or biomass. A Canadian bottom trawl survey occurs on the Scotian Shelf (NAFO Divisions 4VWX) during July. Since the Scotian Shelf survey occurs near the start of the directed fisheries, it can be considered as a pre-fishery relative abundance index for the area surveyed.

NEFSC survey procedures and details of the stratified random sampling design are provided in Azarovitz (1981). Standard survey tows in offshore strata 1-40 and 61-76 (Fig. C8) were used to compute relative abundance and biomass indices which were adjusted for differences in research vessel effects. A vessel conversion coefficient of 0.81 was applied to the *Delaware II* stratified mean weight per tow values, prior to computing the autumn survey indices, to standardize *Delaware II* catches to the *Albatross IV* catches (Hendrickson et al. 1996). Indices of relative abundance (stratified mean number per tow) and biomass (stratified mean weight per tow, in kg) from NEFSC autumn bottom trawl surveys, conducted during 1967-2004 are presented in Figure C9 and Table C6. Indices from NEFSC spring surveys, conducted during March, were also computed for the same strata set used to derive the autumn survey indices. Relative abundance and biomass indices from the Canadian bottom trawl survey, conducted on the Scotian Shelf (NAFO Division 4VWX) during July, are presented with the autumn survey indices for comparative purposes. All survey strata were used in the computations and the indices could not be standardized for gear and vessel changes that occurred in 1982, 1983 and 2004 due a lack of data from comparative fishing experiments (Hendrickson et al 2005).

As might be expected for a sub-annual species with environmental effects on availability and recruitment, all of the survey indices show a large degree of interannual variability. Autumn survey indices suggest that *Illex* relative abundance on the U.S. shelf was high during 1976-1981 and during 1987-1990 (Fig. C9). Autumn survey abundance indices were at or below the 1982-2003 average during 1991-1997. Abundance indices increased in 1998, but then declined to the second lowest level on record in 1999 (Table C6), following the high level of landings taken in 1998 (Table C1). During 1999-2002, abundance indices increased gradually during a period of low fishing effort (NEFSC 2003). Relative abundance reached the highest level on record in 2003 (28 squid per tow), then declined to below the 1982-2003 average in 2004, coincident with the highest landings on record for the U.S. stock component.

NEFSC spring survey indices are more variable than those from the autumn survey due to variability in the timing of *Illex* migrations onto the shelf in the spring. However, a notable trend is the spike in abundance and biomass indices that occurred during 1997 and 1998. Although this spike coincided with a 1998 spike in domestic landings, a similar spike in the spring abundance

index did not occur in 2004, the year of the highest U.S. landings on record (Fig. C10A, Table C1). The 2005 spring survey index was very low and similar to the 2003 level.

The Canadian Scotian Shelf survey indices do not appear to track either the spring or autumn surveys of the USA Shelf. Similar to the NEFSC autumn survey indices, the Canadian survey indices also showed a peak in abundance and biomass during 1976, but not for an extended period of time (Figs. C10B and C10C). Based on an extended period of low *Illex* biomass in the July Scotian Shelf surveys and smaller than average body size (Fig. C11A), since 1982, the SA 3+4 component of the stock has been characterized as being in a low productivity regime (Hendrickson et al. 2005). The average body size of *Illex* caught in the NEFSC autumn surveys has also been much lower since 1982 and was below the 1982-2003 average during 2000-2004 (Fig. C11B). Average body size in the NEFSC spring survey was at or below the 1982-2003 average during 1995-2004 (Fig. C11C). These long-term observed difference in mean weights may be due to differing contributions of seasonal cohorts or differing growth conditions during these periods.

The migration of *Illex* squid into northern fishing areas off Newfoundland is affected by oceanographic conditions (Rowell et al. 1985; Dawe and Warren 1992; Dawe et. al. 1998). The autumn distribution of *Illex* on the U.S. shelf is also affected by water temperature conditions and bottom temperatures ranging from 9-13°C are preferred (Brodziak and Hendrickson 1999). The Mid-Atlantic Bight serves as important *Illex* habitat during spring through autumn (Hendrickson and Holmes 2004). Areal average surface and bottom temperature anomalies indicate that spring and autumn water temperatures in the Mid-Atlantic Bight have generally been warmer during 1982-2003 than during the reference period of 1977-1987 (Fig. C12) (Holzwarth and Mountain 1990; Holzwarth-Davis and Taylor 1992, 1993 and 1994; Taylor and Almgreen 1996a and 1996b; Taylor and Kalidas 1997; Taylor and Bascunan 1998, 1999, 2000 and 2001; Taylor et. al. 2002). *Illex* relative abundance and biomass indices from the autumn surveys and spring average body weights, for 1982-2002, are significantly negatively correlated with bottom water temperature anomalies from the autumn surveys (NEFSC 2003). However, interpretation of these results is complicated because spring and autumn bottom water temperature anomalies are correlated so additional research on this topic is needed.

Depth transect surveys were conducted seasonally during 2003-2005 by Rutgers University with funding from the Research Set-aside Program of the Mid-Atlantic Fishery Management Council (MAFMC). Survey data were available for January (2004 and 2005), March (2003-2005), May (2003 and 2004) and November (2004). However, only the May data are relevant to the *Illex* stock because *Illex* does not consistently inhabit the U.S. Shelf during the other survey months (Black et al. 1987; Hendrickson 2004). *Illex* catch rates were examined from the May bottom trawl surveys, conducted along two transects located near Hudson and Baltimore Canyons, to determine what proportion of the survey catches occurred at depths beyond the limit of the majority of the NEFSC autumn survey stations (about 185 m). However, the data could not be used to evaluate *Illex* abundance by depth because declines in catch rates coincided with the depth beyond which sampling occurred at night (274 m), when *Illex* is distributed in the upper layer of the water column and not available to bottom trawl gear (Brodziak and Hendrickson 1999).

Fishery Catch per Unit of Effort Indices

The in-season pattern of CPUE reflects the balance of recruitment, fishing and natural mortality, and emigration from the fishing area (Caddy 1991). In Caddy's formulation, the boundaries between these processes are sharp and are assumed to induce point changes in the slope of log CPUE versus time. Implementation of an in-season depletion model would require an ability to detect such point changes in the CPUE trends. However, a declining trend in weekly LPUE data from the U.S. *Illex* fishery is not detectable in some years (NEFSC 1999). In order to better understand LPUE trends, spatial changes in fishing patterns were evaluated and the effects of various factors on the standardization of fishing effort were assessed. Since *Illex* discards for the U.S. fishery are low in comparison to *Illex* landings (refer to the above section on discards), LPUE is considered to be representative of CPUE.

Fishing Effort

Fishing effort in the *Illex illecebrosus* fishery is affected by catch values determined largely by the global squid market, particularly the Falklands squid fisheries, and the abundance of *Illex* on the U.S. Shelf. The *Illex* fishery is a volume-based fishery and effort patterns vary for the two fleet sectors involved in the directed fishery, refrigerated seawater system trawlers (RSW vessels) and freezer trawlers (FT vessels). The RSW vessels tend to be of smaller size than the freezer trawlers and store their catches in chilled seawater. Both factors result in shorter trips, generally less than four days, than those made by FT vessels (up to 14 days) which are larger and freeze their catches at sea. The home ports for FT vessels are North Kingston and Point Judith, Rhode Island and Cape May, New Jersey. Effort patterns for the RSW fleet are primarily determined by the travel distance between a shoreside processing facility and the offshore fishing grounds. The home port for most of the RSW vessels is Cape May, New Jersey, where there is a major *Illex* processing facility, but other home ports include Wanchese, North Carolina, Hampton Roads, Virginia and several Rhode Island ports (MAFMC 1998c).

The fleet size is small, generally less than 30 vessels, but the number of vessels participating in the fishery is highly variable from year-to-year. During 1999 and 2004, participation in the fishery was high (27-28 vessels) and during 2000-2003 participation was much lower (10-14 vessels, Fig. C13A). During 1999-2003, most of the annual landings (> 75%) were from freezer trawlers. However, in 2004, the proportion of annual landings for each fleet sector was nearly equal (Fig. C13B). This was primarily a result of an increased number of short duration trips (355 trips lasting 1.8 days on average) conducted by RSW vessels (Table C7, Fig. C13C).

Total nominal effort for both fleet sectors combined was twice as high in 2004 as in 2003, despite a shorter fishing season (five fewer weeks), and may have been higher if the fishery was not closed on September 21 (Table C7). In-season trends in weekly effort were different for the two fleet sectors during 2003 and 2004. During 2003, only three freezer trawlers fished for *Illex*, so the number of FT trips was fairly constant throughout the fishing season (Fig. C14A). The weekly trend in the number of days fished by FT vessels varied without trend in 2003 and was very erratic due to the duration (8.2 days on average) and timing of the trips which tend to start and end on the same day of the week (Fig. C14B). During 2004, twelve FT fished and the number of trips gradually increased throughout the fishing season until the fishery was closed (Fig. C14C). The number of days fished by FTs in 2004 increased between weeks 20-30 then varied without trend until the fishery closure (Fig. C14D). In contrast, weekly trends in the

number of RSW trips was similar to weekly trends in the number of days fished, for 2003 and 2004, due to the short trip durations (1.8-2.8 days). During both years, a definite trend of increasing effort, which peaked at week 35, was followed by a decline. In 2003, a second rise and fall pattern was observed between weeks 37 the end of the RSW fishery (week 44). It was suggested at the Working Group meeting, that the decline in RSW effort (trips and days fished) which occurred three weeks prior to the fishery closure, during week 35, was a result of a unimplemented plan for an early-season closure of the Cap May processing facility.

A geographic information system (GIS) was used to examine the spatial distribution of effort in the *Illex* fishery, by quarter-degree square (QDSQ), during 2003 and 2004. The spatial distribution of fishing effort also varied by fleet sector. During 2003, freezer trawler effort was concentrated in several QDSQs, while RSW effort occurred across a broader area. In 2003, there was little spatial overlap between the most heavily fished QDSQs by the two fleet sectors (Fig. C15). For QDSQs that were consistently fished in 2003, the monthly effort pattern showed a rise and fall trend (Fig. C16). In contrast to 2003, fishing effort by both fleet sectors was concentrated off Cape May, New Jersey in 2004 (Fig. C17). Effort that occurred further south was primarily attributable to RSW vessels. In 2004, there was a high degree of spatial overlap between the most heavily-fished QDSQs of both fleet sectors. Within the three QDSQs with the highest effort concentrations, a monthly rise and fall pattern of effort is observed for the RSW vessels. FT effort was more constant throughout the season in QDSQs 38731 and 38733 (Fig. C18).

Trends in LPUE

As discussed in the Landings section, trends in weekly landings from the Weighout database closely matched those from the VTR database for 2003 and 2004. As a result, nominal LPUE was computed as the sum of the weekly effort (days fished) from the VTR Database divided by the sum of the weekly landings (mt) from the VTR Database. Weekly trends in nominal LPUE for RSW vessels showed a clear rise and fall pattern during 2003 and 2004, but weekly catch rates of FT vessels did not (Fig. C19). During 2003 (a year of low FT effort), FT catch rates showed several rise and fall periods with a peak during week 31, while RSW catch rates gradually increased during weeks 24-38, then declined thereafter. During 2004, RSW vessels began fishing one week earlier than FT vessels. RSW catch rates increased rapidly during weeks 20-23, then gradually increased between weeks 24 and 34. After week 34, but prior to closure of the fishery (week 38), there was a decline in RSW catch rates which occurred one week prior to the decline in the number of RSW trips and days fished (Fig. C14). FT catch rates reached a peak during the first few weeks of the fishery (week 22) then remained fairly constant during weeks 23-34. After week 34, FT catch rates also declined. However, it cannot be assumed that the decline in catch rates after week 34 were due to declining *Illex* abundance because of the confounding of reduced fishing effort during this time as a result of the proposed processing facility closure.

Spatial trends in nominal LPUE, for the entire *Illex* fleet, were very different between 2003 and 2004. High catch rates occurred across a larger area in 2004 than in 2003 and this may suggest much higher *Illex* abundance in 2004 (Fig. C20). Fairly high catch rates also occurred near the shelf edge located off southern New England. During 2003, monthly catch rates were highest in July and were consistently high in southern areas (35° 30' to 37° N), and (Fig. C21). During 2004, monthly catch rates were consistently high near the shelf edge off Cape May, and the area

of high catch rates increased in size during July and August (Fig. C22). Fishing in the southern New England area occurred in August. A sequential rise and fall pattern in the combined catch rates of all vessels occurred in three different QDSQs during the 2003 fishing season, but it is unclear whether this represented localized depletion (Fig. C23A). During 2004, weekly trends in catch rates were similar for three FTs fishing in two different QDSQs (Fig. C24B) and the catch rates of several RSW vessels and a FT fishing within the same QDSQ all showed similar trends (Fig. C24C). These trends suggest that depletion may be possible within QDSQs during periods of high effort by both fleet sectors.

Standardization of the effort used to compute LPUE was conducted in order to determine whether this would improve the ability to detect a declining trend in weekly catch rates. A three-factor, main effects General Linear Model (GLM) was applied to log-transformed LPUE data (mt per day fished) for 2003 and 2004. LPUE was computed using the VTR landings for 2003. The WO landings were used to compute LPUE for 2004 because weekly landings data presented during the Working Group meeting suggested underreporting of VTR landings for 2004. For 2004, the VTR and WO data were matched by hull number, month and day (using the date sold field) and the VTR landings were replaced with the WO landings. This matched data set accounted for 72% of the WO landings. The trips that did not match were prorated to week of the year and QDSQ based on the ratios of the matched trips. The proration accounted for an additional 16% of the WO landings. The remainder of the trips could not be used because they had missing effort values, QDSQs, or both. As in previous assessments, directed trips used in the GLM were defined as otter trawl trips that occurred during May through November and that landed at least 25%, by weight, of *Illex*. Factors included in the GLM included: week of the year, quarter-degree, and either vessel type (RSW or freezer trawler) or hull number. Final model runs included the factors: vessel type, quarter-degree square and week of the year (Table C8 and C9). A summary of the various GLM runs is presented in Table C10. For the final 2004 models run, all three model effects were highly significant ($p < 0.0001$), but the influence of spatial effects (quarter-degree square) on LPUE was not significant in 2003. Weekly standardized fishing effort was highly variable in 2003 (Fig. C24A) and standardized LPUE did not show a rise and fall trend. Standardized effort for 2004 indicated an increasing trend which reached a peak in week 35 then declined (Fig. C24B). Nominal LPUE showed a similar trend (Fig. C25A), but the trend was removed when LPUE was computed using standardized effort (Fig. C25B).

5.0 ESTIMATION OF NATURAL MORTALITY

Maturation-Natural Mortality Model

(EDITOR'S NOTE: THIS PART OF THE WORKING GROUP REPORT REFERS TO APPENDIX C3 WHICH HAS BEEN OMITTED. REFER TO HENDRICKSON AND HART [2006], FOR MODEL RESULTS).

Based on a review of the model results, the Working Group decided that the estimates of natural mortality were preliminary. They acknowledged that the model formulation was sound and appropriate given the semelparous life history of the species, but that natural mortality estimates may vary during the fishing season because growth rates increase seasonally for squid from the northern stock component (Dawe and Beck 1997). The Working Group recommended that new data on growth and maturity be obtained for inclusion in future model runs.

6.0 BIOLOGICAL REFERENCE POINTS

The Amendment 8 control rule states that when the stock biomass exceeds B_{MSY} , the overfishing threshold is F_{MSY} , and target F is 75% of F_{MSY} . Below B_{MSY} , target F decreases linearly and is set to zero when stock size is at the biomass threshold of $\frac{1}{2}B_{MSY}$. Amendment 8 specifies B_{MSY} as 39,300 mt and F_{MSY} as 1.22 per year.

Reference points that minimize the risk of recruitment overfishing, by ensuring that escapement exceeds a threshold minimum spawning stock biomass or number of eggs per recruit, have been considered to be the most appropriate for annual squid stocks that exhibit highly variable trends in interannual recruitment (Beddington et al. 1990). The current MSY-based biological reference points were based on a biomass dynamics model which estimated MSY at 24, 274 mt (NEFSC 1996). However, bootstrap analyses indicated poor precision of r , q and K estimates and the model assumption of constant natural mortality rate is invalid for *I. illecebrosus*. Given these considerations, %MSP-based proxies for MSY-based reference points are recommended. Further, the source of the reference point proxies should be derived from a model that accounts for the semelparous life history of *Illex*.

Yield-per-recruit and egg-per-recruit models

A semelparous life history model was derived to estimate yield-per-recruit (YPR) and the number of eggs-per-recruit (EPR) for a cohort of female squid as a function of fishing mortality (Hendrickson and Hart 2006). Consistent with the maturation-mortality model, the YPR and EPR models track females in two bins: the number of immature females, N_t , and the number of mature females, S_t . At each weekly time step, immature individuals have four possible fates: (1) death due to either non-spawning natural mortality, M_{NS} , (e.g., from predation, which is assumed to occur at a constant rate) or (2) death due to fishing mortality (calculated as $F_t = F\theta_t$, where θ_t is the fishery selectivity of the individuals of age t weeks); (3) survival to the next week either as an immature individual; or (4) survive and mature at rate P_t .

Biological reference point estimates derived from the egg-per-recruit and yield-per-recruit models were presented. However, the potential reference point proxies estimated using the EPR model were considered preliminary by the SARC 42 Working Group because they included estimates of natural mortality that were considered preliminary. In addition, seasonal changes in growth rates are likely for this species and this will affect the reference point estimates (Figure C26). Therefore, seasonal growth rate data are required to test the sensitivity of the per-recruit models to growth rates.

(EDITOR'S NOTE: THIS PART OF THE WORKING GROUP REPORT REFERS TO APPENDIX C4 WHICH HAS BEEN OMITTED) (see Hendrickson and Hart 2006).

7.0 STOCK SIZE AND FISHING MORTALITY RATES

In-season Assessment Model

The short life cycles, rapid growth rates, highly variable population abundance, high natural mortality rates and semelparous breeding strategies of most cephalopod species render many of the traditional annual-based approaches to stock assessment inappropriate (Caddy 1983). This is certainly the case for the *I. illecebrosus* stock, for which biomass dynamics models provide very imprecise estimates of stock size and fishing mortality rates (NEFSC 1996; Hendrickson et. al. 1996) which is likely attributable to the fact that cephalopod population dynamics do not conform to the underlying model assumptions (Pierce and Guerra 1994). Assessment of the *Illex* stock is hindered by the lack of research survey biomass and abundance indices for the USA stock component and the stock as a whole. Annual-based modeling approaches are inappropriate for a species with a lifespan of less than one year.

Within-season depletion models have been found to offer the most promise for assessing ommastrephid and loliginid squid stocks (Anon. 1999; Pierce and Guerra 1994) and have been used since 1987 to assess the Falkland Islands stocks of *Illex argentinus* and *Loligo gahi* (Rosenberg et. al. 1990; Agnew et al. 1998). Depletion estimation requires data consisting of: total catch, mean body weights, an abundance index (e.g., CPUE), a recruitment index proportional to the number of recruits, and an estimate of natural mortality. In addition, these data must be of appropriate temporal and spatial resolution, tow-based, and available throughout the fishing season.

During the previous *Illex* assessment at SARC 37 (NEFSC 2003), the in-season assessment model developed for SARC 29 (NEFSC 1999) was revised to include a recruitment index and an objective function. The model, which estimates weekly fishing mortality rates and initial stock size, was run using tow-based catch, effort and fishing location data instead of VTR data. During the current assessment, the SARC 37 model was further revised to allow for the possibility of fitting one of the maturity ogive parameters, α , together with F_{TOT} and N_0 .

Both Working Groups felt that the SARC 42 model formulation (Appendix C5) was sound but that the model results should not be used to update fishing mortality and stock size estimates because:

1. A major model uncertainty is the use of a May growth curve which underestimates growth later in the fishing season. Despite scaling up the asymptotic length by using a percentile of the observed lengths from the fishery data, empirical length-at-age data must be collected and analyzed to determine seasonal changes in growth rate
2. The method of computing the weekly recruitment indices requires further investigation
3. Sensitivity analyses for various values of initial stock size, using 1999 and 2003 data, indicated that a broad range of N_0 and F_{TOT} values were plausible, suggesting a flat estimation surface. The Working Group felt that additional simulation testing would be beneficial in understanding how varying the model parameters affect the model results.

8.0 CONCLUSIONS

Abundance and biomass indices

Seasonal bottom trawl surveys of the USA shelf do not cover the geographic distribution of the USA stock component. *Illex* inhabit areas outside the range of the USA surveys based on data from other research surveys and fisheries data. The USA autumn survey may serve as an index of spawner escapement but for a cohort other than that which is fished at the start of the *Illex* fishing season. Furthermore, it is unknown whether autumn survey trends are due to low abundance, low availability or both. The relative abundance index for the US autumn survey was the highest on record in 2003 and very low in 2004 following the highest landings on record. Further research is needed to determine the association between fishery catch rates and *Illex* abundance.

Fishery Characteristics

Body size is likely related to productivity. *Illex* landed during 2004 were larger in size than those landed during most years since 1994. The number of vessels and trips that occurred in 2004 were much higher than any year since 2000 and landings reached a record high of 26,087 mt, which exceeded the quota and resulted in an early closure of the fishery. Landings and effort in 2003 were much lower than in 2004 and body size (an indicator of productivity) was also smaller, similar to the trends for 1999-2002. Preliminary U.S. fishery landings for 2005 are 11, 429 mt.

Estimation of fishing mortality and stock size

The in-season model estimates of fishing mortality and stock size were not considered reliable because new data on seasonal growth rates and maturity are required for the model. Use of the May growth curve underestimates growth later in the season.

Stock status

Stock status cannot be determined because adequate data are not available to estimate fishing mortality rates and absolute stock size.

9.0 RESEARCH RECOMMENDATIONS PAST AND PRESENT

The status of research recommendations from the previous *Illex* assessment, conducted at SARC 37, is presented in Table C11. Based on reviews of the current assessment, it was concluded at both Subcommittee meetings that the most important research recommendation involves the collection and analysis of seasonal age and maturity. Without these data, assessment of the stock using the models contained herein will not be possible. In order of priority, specific research recommendations from the current assessment are as follows:

1. All of the models presented require additional data collection. Maturity and age data should be collected throughout the fishing season to evaluate the effects of differential growth and maturity within seasons and between years. Emphasis should be placed on the

collection of weekly data. The in-season model would be improved with tow-based catch, effort and fishing location data, particularly if collected electronically in real-time.

2. Re-estimate M_{ns} and M_{sp} for females from each seasonal cohort and determine whether M_{ns} and M_{sp} estimates for males are similar to those of females.
3. Re-estimate biological reference points for each seasonal cohort by incorporating seasonal information regarding growth, selectivity, and natural mortality.
4. The in-season assessment model results show a high sensitivity to parameters such as growth and recruitment, so additional simulation analyses are needed to determine the range of possible responses by the model. The simulation analyses should reflect the actual reality of the fishery and data input/output (such as fishery length frequencies for estimating partial recruitment). Length data rather than age data should be utilized in the simulation model so that the simulation formulation is identical to that used in the in-season model.
5. Further exploration of relationships between oceanographic conditions and abundance and body size of squid on the US Shelf is needed to determine whether a pre-season predictor variable for abundance or stock productivity can be found.
6. It is important to know what fraction of the stock inhabits waters deeper than 185 m, particularly during May and in the fall. Seasonal transect surveys are conducted by Rutgers University with Mid-Atlantic research funds in order to monitor the seasonal depth distribution of Mid-Atlantic species. Although *Illex* is not a “target” species, abundance and length frequency data are collected. However *Illex* abundance by depth could not be determined from these surveys because diel migration patterns were confounded with the sampling protocol. Therefore, it would be useful to conduct some adaptive or fixed stations for determining *Illex* abundance and length composition, during daylight hours, at depths beyond 185 m during May and in the fall.
7. A pre-fishery, stratified random survey would be useful to estimate initial stock size.
8. Evaluate the utility of relative abundance and biomass indices from the NEFSC winter survey.

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11.0 REFERENCES

- Agnew, D.J., J.R. Beddington, R. Baranowski, S. des Clers, and C.P. Nolan. 1998. Approaches to assessing stocks of *Loligo gahi* around the Falkland Islands. Fish. Res. 35: 155-169.
- Anonymous. 1999. Report of the working group on cephalopod fisheries and life history. ICES CM 1999/G:4.
- Applegate, A, S. Cadrin, J. Hoenig, C. Moore, S. Murawski and E. Pikitch. 1998. Evaluation of existing overfishing definitions and recommendations for new overfishing definitions to comply with the Sustainable Fisheries Act. Final Report. 179 p.
- ASMFC [Atlantic States Marine Fisheries Commission]. 1994. Assessment report for Gulf of Maine northern shrimp, 1994.
- Azarovitz, T.R. 1981. A brief historical review of the Woods Hole Laboratory trawl survey time series. In: Doubleday, W.G. and Rivard, D. (Eds.) Bottom trawl surveys. *Canadian Special Publication of Fisheries and Aquatic Sciences* 58, p. 62-67.
- Basson, M., J.R. Beddington, J.A. Crombie, S.J. Holden, L.V. Purchase and G.A. Tingely. 1996. Assessment and management techniques for migratory annual squid stocks: the *Illex argentinus* fishery in the southwest Atlantic as an example. Fish. Res., 28:3-27.
- Beddington, J.R., A.A. Rosenberg, J.A. Crombie and G.P. Kirkwood. 1990. Stock assessment and the provision of management advice for the short fin squid fishery in Falkland Island waters. Fish. Res., 8:351-365.
- Black, G.A.P., T.W. Rowell, and E.G. Dawe. 1987. Atlas of the biology and distribution of the squids *Illex illecebrosus* and *Loligo pealei* in the Northwest Atlantic. Can. Spec. Publ. Fish. Aquat. Sci. 100: 62 p.
- Brodziak, J. and L.C. Hendrickson. 1999. An analysis of environmental effects on survey catches of squids, *Loligo pealei* and *Illex illecebrosus*, in the Northwest Atlantic. Fish. Bull. 97:9-24.
- Caddy, J. F. 1983. The cephalopods: factors relevant to their population dynamics and to the assessment and management of stocks. In J. F. Caddy, Ed. Advances in assessment of world cephalopod resources, p. 416-452. FAO Fish. Tech. Pap. No. 231. Rome.
- Caddy, J. F. 1991. Daily rings on squid statoliths: an opportunity to test standard population models? In: Jereb, P.S., S. Ragonese, and S. von Boletzky. (Eds.) *Squid age determination using statoliths*. Proceedings of the International Workshop held in the Istituto di Tecnologia della Pesca e del Pescato (ITPP-CNR), Mazara del Vallo, Italy, 9-14 October, 1989. N.T.R.-I.T.P.P. Special Publication No. 1, pp. 53-66.
- Coelho M.L. and R.K. O'Dor. 1993. Maturation, spawning patterns and mean size at maturity in the short-finned squid *Illex illecebrosus*. p. 81-91. In: Okutani T., O'Dor R.K. and

- Kubodera T. (eds.) *Recent Advances in Cephalopod Fisheries Biology*. Takai University Press, Tokyo, XV + 752 p.
- Dawe, E.G. 2003. Personal communication. Department of Fisheries and Oceans. St. John's, Newfoundland.
- Dawe, E.G. and W. Warren. 1992. Recruitment of short-finned squid in the Northwest Atlantic Ocean and some environmental relationships. *J. Ceph. Biol.* 2(2): 1-21.
- Dawe, E.G., and P.C. Beck. 1997. Population structure, growth and sexual maturation of short-finned squid (*Illex illecebrosus*) at Newfoundland. *Can. J. Fish. Aquat. Sci.*, 54: 137-146.
- Dawe, E.G., and L. C. Hendrickson. 1998. A review of the biology, population dynamics, and exploitation of short-finned squid in the Northwest Atlantic Ocean in relation to the assessment and management of the resource. NAFO SCR. Doc. 98/59, Ser. No. N3051.
- Dawe, E.G., R.K. O'Dor, P.H. Odense, and G.V. Hurley. 1985. Validation and application of an ageing technique for short-finned squid (*Illex illecebrosus*). *J. Northw. Atl. Fish. Sci.* 6:107-116.
- Dawe, E.G., E.B. Colburne and K.F. Drinkwater. 1998. Environmental regulation on short-finned squid recruitment to Canadian fishing areas. NAFO SCR Doc. 98/54, Ser. N3045.
- Durward, R.D., T. Amaratunga and R.K. O'Dor. 1979. Maturation index and fecundity for female squid, *Illex illecebrosus* (LeSueur, 1821). *ICNAF Res. Bull.* 14: 67-72.
- Forsythe, J.W. and W.F. van Heukelem. 1987. Growth. *In: P. R. Boyle (Ed.) Cephalopod Life Cycles, Vol. II.* Acad. Press Inc. (London) Ltd. pp 135-156.
- Goodwin, Glenn. 1999. Personal Communication. Captain of F/V *Relentless*. Davisville, RI.
- Hendrickson, L.C. 2004. Population biology of northern shortfin squid (*Illex illecebrosus*) in the northwest Atlantic Ocean and initial documentation of a spawning site in the Mid-Atlantic Bight (USA). *ICES J. Mar. Sci.* 61: 252-266.
- Hendrickson, L.C. and D. R. Hart. 2006. An age-based cohort model for estimating the spawning mortality of semelparous cephalopods with an application to per-recruit calculations for the northern shortfin squid, *Illex illecebrosus*. *Fish. Res.* 78: 4-13.
- Hendrickson, L. C. and E. M. Holmes. 2004. Essential fish habitat source document: northern shortfin squid, *Illex illecebrosus*, life history and habitat characteristics, Second Edition. NOAA Tech. Memo. NMFS-NE-191. 36 p.
- Hendrickson, L.C., J. Brodziak, M. Basson, and P. Rago. 1996. Stock assessment of northern shortfin squid, *Illex illecebrosus*, in the Northwest Atlantic during 1993. *Northeast Fish. Sci. Cent. Ref. Doc.* 96-05g; 63 p.

- Hendrickson, L.C., E.G. Dawe and M.A. Showell. 2004. Assessment of northern shortfin squid (*Illex illecebrosus*) in Subareas 3+4 for 2003. NAFO SCR Doc. 04/38. Ser. No. N4989. 18 p.
- Hendrickson, L.C., E.G. Dawe and M.A. Showell. 2005. Interim monitoring report for the assessment of northern shortfin squid (*Illex illecebrosus*) in Subareas 3+4 during 2004. NAFO SCR Doc. 05/45. Ser. No. N5131. 9 p.
- Hendrickson, L.C., D.A. Hiltz, H.M. McBride, B.M. North and J.E. Palmer. 2003. Implementation of electronic logbook reporting in a squid bottom trawl study fleet during 2002. Northeast Fish. Sci. Cent. Ref. Doc. 03-07; 30 p.
- Holzwarth, T.J. and D. Mountain. 1990. Surface and Bottom Temperature Distributions from the Northeast Fisheries Center Spring and Fall Bottom Trawl Survey Program, 1963-1987. Northeast Fish. Sci. Cent. Ref. Doc. 90-03.
- Holzwarth-Davis, T.J. and M. Taylor. 1992. Description of the 1991 Oceanographic Conditions on the Northeast Continental Shelf. Northeast Fish. Sci. Cent. Ref. Doc. 92-08.
- Holzwarth-Davis, T.J. and M. Taylor. 1993. Description of the 1992 Oceanographic Conditions on the Northeast Continental Shelf. Northeast Fish. Sci. Cent. Ref. Doc. 93-25.
- Holzwarth-Davis, T.J. and M. Taylor. 1994. Description of the 1993 Oceanographic Conditions on the Northeast Continental Shelf. Northeast Fish. Sci. Cent. Ref. Doc. 94-11.
- Hurley, G.V., P. Odense, R.K. O'Dor and E.G. Dawe. 1985. Strontium labelling for verifying daily growth increments in the statoliths of the short-finned squid (*Illex illecebrosus*). Can. J. Fish. Aquat. Sci. 42:380-383.
- Jossi, J.W. and R. L. Benway. 2003. Variability of temperature and salinity in the Middle Atlantic Bight and Gulf of Maine based on data collected as part of the MARMAP Ships of Opportunity Program, 1978-2001. NOAA Tech. Memo. NMFS-NE-172.
- Laptikhovsky, V. V. and C. M. Nigmatullin. 1993. Egg size, fecundity and spawning in females of the genus *Illex* (Cephalopoda: Ommastrephidae). ICES J. Mar Sci. 50:393-403.
- Lange, A. M. T. 1981. Yield-per-recruit analyses for squid, *Loligo pealei* and *Illex illecebrosus*, from the Northwest Atlantic. J. Shell. Res. 1(1): 197-207.
- Lange, A.M.T., and M.P. Sissenwine. 1980. Biological considerations relevant to the management of squid *Loligo pealei* and *Illex illecebrosus* of the Northwest Atlantic. Mar. Fish. Rev. 42(7-8):23-38.
- Lange, A.M.T., M.C. Ingham and C.A. Price. 1984. Distribution of maturing *Illex illecebrosus* relative to the shelf-slope front of the northeastern United States. NAFO SCR Doc. 84/IX/109, Ser. No. N906. 18 p.

- Mercer, M.C. 1973. Sexual maturity and sex ratios of the ommastrephid squid *Illex illecebrosus* (LeSueur) at Newfoundland (Subarea 3). ICNAF Res. Doc. 73/71, Ser. No. 3024. 14 p.
- Mid-Atlantic Fishery Management Council. 1994. Optimum yield, domestic annual harvest, domestic annual processing, joint venture processing, and total allowable level of foreign fishing for Atlantic Mackerel, *Loligo*, *Illex*, and Butterfish for 1995.
- Mid-Atlantic Fishery Management Council. 1995a. Optimum yield, domestic annual harvest, domestic annual processing, joint venture processing, and total allowable level of foreign fishing for Atlantic Mackerel, *Loligo*, *Illex*, and Butterfish for 1996.
- Mid-Atlantic Fishery Management Council. 1995b. Amendment 5 to the Fishery Management Plan and the Final Environmental Impact Statement for the Atlantic Mackerel, Squid and Butterfish Fisheries. 168 p.
- Mid-Atlantic Fishery Management Council. 1996a. Optimum yield, domestic annual harvest, domestic annual processing, joint venture processing, and total allowable level of foreign fishing for Atlantic Mackerel, *Loligo*, *Illex*, and Butterfish for 1997.
- Mid-Atlantic Fishery Management Council. 1996b. Resubmitted portion of Amendment 5 to the Fishery Management Plan for the Atlantic Mackerel, Squid and Butterfish Fisheries. 38 p.
- Mid-Atlantic Fishery Management Council. 1996c. Amendment 6 to the Fishery Management Plan for the Atlantic Mackerel, Squid and Butterfish Fisheries. 17 p. + Appendices.
- Mid-Atlantic Fishery Management Council. 1997a. Optimum yield, domestic annual harvest, domestic annual processing, joint venture processing, and total allowable level of foreign fishing for Atlantic Mackerel, *Loligo*, *Illex*, and Butterfish for 1998.
- Mid-Atlantic Fishery Management Council. 1998a. Optimum yield, domestic annual harvest, domestic annual processing, joint venture processing, and total allowable level of foreign fishing for Atlantic Mackerel, *Loligo*, *Illex*, and Butterfish for 1999.
- Mid-Atlantic Fishery Management Council. 1998b. Amendment 7 to the Fishery Management Plan for the Atlantic Mackerel, Squid and Butterfish Fisheries. 33 p. + Appendices.
- Mid-Atlantic Fishery Management Council. 1998c. Amendment 8 to the Fishery Management Plan for the Atlantic Mackerel, Squid and Butterfish Fisheries. 351 p. + Appendices.
- Mid-Atlantic Fishery Management Council. 2000. Optimum yield, domestic annual harvest, domestic annual processing, joint venture processing, and total allowable level of foreign fishing for Atlantic Mackerel, *Loligo*, *Illex*, and Butterfish for 2001.
- Mid-Atlantic Fishery Management Council. 2001. Optimum yield, domestic annual harvest, domestic annual processing, joint venture processing, and total allowable level of foreign fishing for Atlantic Mackerel, Squid and Butterfish for 2002.

- Mid-Atlantic Fishery Management Council. 2002. Optimum yield, domestic annual harvest, domestic annual processing, joint venture processing, and total allowable level of foreign fishing for Atlantic Mackerel, Squid and Butterfish for 2003.
- NAFO [Northwest Atlantic Fisheries Organization] 1980. Canadian proposal for international regulation of the fisheries for squid (*Illex*) in Subareas 3 and 4 of the Convention Area. NAFO Fisheries Commission Document 80/III/4, Ser. No. N085.
- NAFO [Northwest Atlantic Fisheries Organization]. 1995. Scientific Council Reports, 1994. pp. 116-117.
- NAFO [Northwest Atlantic Fisheries Organization]. 1999. Scientific Council Reports, 1998. 257 p.
- NAFO [Northwest Atlantic Fisheries Organization]. 2000. Scientific Council Reports, 1999. 303 p.
- NEFC. 1990. Report of the Spring 1990 NEFC Stock Assessment Workshop (Tenth SAW). NOAA\NMFS\NEFC: Woods Hole, MA. NEFC [Northeast Fisheries Center] Ref. Doc. 90-07.
- Northeast Fisheries Science Center (NEFSC). 1991. Report of the Twelfth Northeast Regional Stock Assessment Workshop, Spring, 1991. NOAA\NMFS\NEFC: Woods Hole, MA. NEFSC Ref. Doc. 91-03.
- Northeast Fisheries Science Center (NEFSC). 1992. Report of the Fourteenth Northeast Regional Stock Assessment Workshop: Stock Assessment Review Committee (SARC) Consensus Summary of Assessments. NOAA\NMFS\NEFC: Woods Hole, MA. NEFSC Ref. Doc. 92-07. 140 p.
- Northeast Fisheries Science Center (NEFSC). 1994. Report of the Seventeenth Northeast Regional Stock Assessment Workshop: Stock Assessment Review Committee (SARC) Consensus Summary of Assessments. NOAA\NMFS\NEFSC: Woods Hole, MA. NEFSC Ref. Doc. 94-06. 124 p.
- Northeast Fisheries Science Center (NEFSC). 1996. Report of the 21st Northeast Regional Stock Assessment Workshop (21st SAW): Stock Assessment Review Committee (SARC) Consensus Summary of Assessments. NEFSC Ref. Doc. 96-05d. 200 p.
- Northeast Fisheries Science Center (NEFSC). 1999. Report of the 29th Northeast Regional Stock Assessment Workshop (29th SAW): Stock Assessment Review Committee (SARC) Consensus Summary of Assessments. NEFSC Ref. Doc. 99-14. 347 p.
- Northeast Fisheries Science Center (NEFSC). 2003. Report of the 37th Northeast Regional Stock Assessment Workshop (37th SAW): Stock Assessment Review Committee (SARC) Consensus Summary of Assessments. NEFSC Ref. Doc. 03-16. 597 p.

- O'Dor R.K. and Coelho M.L. 1993. Big squid, big currents and big fisheries. p. 385-396. *In: Okutani T., O'Dor R.K. & Kubodera T. (Eds.) Recent Advances in Cephalopod Fisheries Biology*. Takai University Press, Tokyo, XV + 752 p.
- O'Dor, R.K. and E.G. Dawe. 1998. Chapter 4. *Illex illecebrosus*. *In: P.G. Rodhouse, E.G. Dawe, and R.K. O'Dor (Eds.)*. Squid recruitment dynamics: the genus *Illex* as a model, the commercial *Illex* species and influences of variability. FAO Fish. Tech. Paper 376.
- Pierce, G.J. & Guerra, A., 1994. Stock assessment methods used for cephalopod fisheries. Fish. Res. 21: 255-285.
- Prager, M. 1994. A suite of extensions to a non-equilibrium surplus-production model. Fish. Bull. 92:374-389.
- Rivard, D., L. C. Hendrickson and F. M. Serchuk. 1998. Yield estimates for short-finned squid (*Illex illecebrosus*) in SA 3-4 from research vessel survey relative biomass indices. NAFO SCR Doc. 98/75.
- Rosenberg, A.A., Kirkwood, G.P., Crombie, J. and Beddington, J.R. 1990. The assessment of stocks of annual squid species. Fish. Res. 8:335-350.
- Showell, M. 1999. Personal communication. Department of Fisheries and Oceans. Bedford Institute of Oceanography. Halifax, NS.
- Rowell T.W., Trites R.W. and Dawe E.G. 1985. Distribution of short-finned squid larvae and juveniles in relation to the Gulf Stream Frontal Zone between Florida and Cape Hatteras. NAFO Sci. Coun. Studies 9: 77-92.
- Taylor, M.H. and D.W. Almgren. 1996a. Description of the 1994 Oceanographic Conditions on the Northeast Continental Shelf. Northeast Fish. Sci. Cent. Ref. Doc. 96-07.
- Taylor, M.H. and D.W. Almgren. 1996b. Description of the 1995 Oceanographic Conditions on the Northeast Continental Shelf. Northeast Fish. Sci. Cent. Ref. Doc. 96-11.
- Taylor, M.H. and M.E. Kiladis. 1997. Description of the 1996 Oceanographic Conditions on the Northeast Continental Shelf. Northeast Fish. Sci. Cent. Ref. Doc. 97-16.
- Taylor, M.H. and C. Bascunan. 1998. Description of the 1997 Oceanographic Conditions on the Northeast Continental Shelf. Northeast Fish. Sci. Cent. Ref. Doc. 98-01.
- Taylor, M.H. and C. Bascunan. 1999. Description of the 1998 Oceanographic Conditions on the Northeast Continental Shelf. Northeast Fish. Sci. Cent. Ref. Doc. 99-01.
- Taylor, M.H. and C. Bascunan. 2000. Description of the 1999 Oceanographic Conditions on the Northeast Continental Shelf. Northeast Fish. Sci. Cent. Ref. Doc. 00-01.
- Taylor, M.H. and C. Bascunan. 2001. Description of the 2000 Oceanographic Conditions on the Northeast Continental Shelf. Northeast Fish. Sci. Cent. Ref. Doc. 01-01.

- Taylor, M.H., C. Bascunan and J.P. Manning. 2002. Description of the 2001 Oceanographic Conditions on the Northeast Continental Shelf. Northeast Fish. Sci. Cent. Ref. Doc. 02-08.
- Trites R.W. 1983. Physical oceanographic features and processes relevant to *Illex illecebrosus* spawning in the western North Atlantic and subsequent larval distribution, NAFO Sci. Studies 6:39-55.

ILLEX TABLES:

Table C1. *Illex illecebrosus* landings (mt) in NAFO Subareas 5+6 (U.S. EEZ) and Subareas 3 and 4 during 1963-2005^{1,2,3,4,5,6} and total allowable catches (TACs).

Year	Cape Hatteras to the Gulf of Maine (Subareas 5+6)			Subareas (3+4)	All Subareas (3-6)	TAC (000's mt)		Percent US Landings
	Domestic	Foreign	Total	Total	Total	3+4	5+6	
	(mt)	(mt)	(mt)	(mt)	(mt)			
1963	810		810	2,222	3,032			
1964	358	2	360	10,777	11,137			
1965	444	78	522	8,264	8,786			
1966	452	118	570	5,218	5,788			
1967	707	288	995	7,033	8,028			
1968	678	2,593	3,271	56	3,327			
1969	562	975	1,537	86	1,623			
1970	408	2,418	2,826	1,385	4,211			
1971	455	6,159	6,614	8,906	15,520			
1972	472	17,169	17,641	1,868	19,509			
1973	530	18,625	19,155	9,877	29,032			
1974	148	20,480	20,628	437	21,065		71	98
1975	107	17,819	17,926	17,696	35,622	25	71	50
1976	229	24,707	24,936	41,767	66,703	25	30	37
1977	1,024	23,771	24,795	83,480	108,275	25	35	23
1978	385	17,207	17,592	94,064	111,656	100	30	16
1979	1,493	15,748	17,241	162,092	179,333	120	30	10
1980	299	17,529	17,828	69,606	87,434	150	30	20
1981	615	14,956	15,571	32,862	48,433	150	30	32
1982	5,871	12,762	18,633	12,908	31,541	150	30	59
1983	9,775	1,809	11,584	426	12,010	150	30	96
1984	9,343	576	9,919	715	10,634	150	30	93
1985	5,033	1,082	6,115	673	6,788	150	30	90
1986	6,493	977	7,470	111	7,581	150	30	99
1987	10,102	0	10,102	562	10,664	150	30	95
1988	1,958	0	1,958	811	2,769	150	30	71
1989	6,801	0	6,801	5,971	12,772	150	30	53
1990	11,670	0	11,670	10,975	22,645	150	30	52
1991	11,908	0	11,908	2,913	14,821	150	30	80
1992	17,827	0	17,827	1,578	19,405	150	30	92
1993	18,012	0	18,012	2,686	20,698	150	30	87
1994	18,350	0	18,350	5,951	24,301	150	30	76
1995	14,058	0	14,058	1,055	15,113	150	30	93
1996	16,969	0	16,969	8,742	25,711	150	21	66
1997	13,629	0	13,629	15,614	29,243	150	19	47
1998	23,597	0	23,597	1,902	25,499	150	19	93
1999	7,388	0	7,388	305	7,693	75	19	96
2000	9,011	0	9,011	366	9,377	34	24	96
2001	4,009	0	4,009	57	4,066	34	24	99
2002	2,750	0	2,750	258	3,008	34	24	91

Table C1. cont.

Year	Cape Hatteras to the Gulf of Maine (Subareas 5+6)			Subareas (3+4) Total (mt)	All Subareas (3-6) Total (mt)	TAC (mt)		Percent US Landings
	Domestic (mt)	Foreign (mt)	Total (mt)			3+4	5+6	
2003	6,389	0	6,389	1,128	7,517	34	24	85
2004	26,087	0	26,087	2,034	28,121	34	24	93
2005	11,429	0	11,429	Not available	11,429	34	24	
Averages								
1976-1981	674	18,986	19,661	80,645	100,306			
1982-1987	7,770	2,868	10,637	2,566	13,203			
1988-1993	11,363	0	11,363	4,156	15,518			
1994-1999	15,665	0	15,665	5,595	21,260			
2000-2003	5,540	0	5,540	452	5,992			

¹ Landings during 1963-1978 were not reported by species, but are proration-based estimates by Lange and Sissenwine (1980)

² Landings during 1979-2003 are from the NEFSC Weighout Database

³ Domestic landings during 1982-1991 include Joint-Venture landings

⁴ Includes landings from Subarea 2

⁵ Landings during 2004 are preliminary for all Subareas; USA landings were reported electronically by dealers during April 2004-2005

⁶ Landings for 2005 include preliminary dealer reports as of 11/2/2005

Table C2. Landings (mt) of *Illex illecebrosus* recorded in the Weighout Database, by gear type, during 1998-2004.

Year	Bottom Trawl	Other ¹ and Unknown	Midwater Pair Trawl	Total	Percent Bottom Trawl
1998	23,567.6	0.5		23,568	100.00
1999	7,387.4	1.2		7,389	99.98
2000	9,011.2	0.1		9,011	100.00
2001	4,008.6	0.0		4,009	100.00
2002	2,724.4	0.0	25.1	2,750	99.09
2003	6,364.4	0.1	26.9	6,391	99.58
2004	25,483.1	546.6		26,030	97.90

¹As of April 2004, gear type data were reported by dealers

Table C3. Estimates of kept weight (mt), discarded weight (mt) and discard ratios (discard/kept weight) of *Illex illecebrosus* sampled in the *Illex* fishery, by observers from the NEFSC Observer Program, during 1995-2004. *Illex* trips were defined as trips where *Illex* landings were $\geq 25\%$, by weight, of the total trip landings. Total discard estimates are the product of discard ratios and total *Illex* landings, for *Illex* trips in the Weighout database, for all months sampled.

	May	June	July	Aug	Sept	Oct	Total
1995							
Trips	0	0	0	0	1	1	2
Total Kept (mt)					0.902	0.113	1.015
Total Discards (mt)					0.007	0.023	0.030
Ratio discard/kept					0.008	0.204	0.030
Total Landings (mt)					1,263.819	905.822	2,169.641
Total Discards (mt)					9.808	184.371	64.127
1996							
Trips	0	4	3	6	1	1	15
Total Kept (mt)		112.696	236.297	182.447	136.617	166.106	834.163
Total Discards (mt)		0.769	3.499	0.045	0.163	0.000	4.476
Ratio discard/kept		0.007	0.015	0.000	0.001	0.000	0.005
Total Landings (mt)		3,817.659	2,736.593	3,787.278	2,455.642	2,436.032	15,233.204
Total Discards (mt)		26.050	40.522	0.936	2.930	0.000	81.741
1997							
Trips	0	0	7	3	0	0	10
Total Kept (mt)			773.388	343.904			1,117.292
Total Discards (mt)			1.941	5.286			7.227
Ratio discard/kept			0.003	0.015			0.006
Total Landings (mt)			5,077.722	3,600.592			8,678.314
Total Discards (mt)			12.744	55.343			56.134

Table C3. cont.

	May	June	July	Aug	Sept	Oct	Total
1998							
Trips	0	0	2	2	0	0	4
Total Kept (mt)			106.141	48.761			154.902
Total Discards (mt)			1.656	0.000			1.656
Ratio discard/kept			0.016	0.000			0.011
Total Landings (mt)			7,526.991	6,501.153			14,028.144
Total Discards (mt)			117.435	0.000			149.970
1999							
Trips	0	0	1	2	1	0	4
Total Kept (mt)			26.218	50.723	14.011		90.952
Total Discards (mt)			0.000	0.907	0.068		0.975
Ratio discard/kept			0.000	0.018	0.005		0.011
Total Landings (mt)			2,249.614	2,550.402	596.029		5,396.045
Total Discards (mt)			0.000	45.605	2.893		57.845
2000							
Trips	0	2	4	7	0	0	13
Total Kept (mt)		85.820	135.459	182.796			404.075
Total Discards (mt)		0.000	0.680	1.198			1.878
Ratio discard/kept		0.000	0.005	0.007			0.005
Total Landings (mt)		1,409.981	2,753.821	2,122.142			6,285.944
Total Discards (mt)		0.000	13.824	13.908			29.215
2001							
Trips	0	0	0	0	0	0	0

Table C3. cont.

	May	June	July	Aug	Sept	Oct	Total
2002							
Trips	0	0	0	0	0	0	0
2003							
Trips	0	1	5	2	1	1	10
Total Kept (mt)		1.950	667.788	294.246	8.393	276.739	1,249.116
Total Discards (mt)		0	2.330	0	00.006	0.232	2.568
Ratio discard/kept		0	0.0003	0	0.001	0.001	0.002
Total Landings (mt)		1,108.513	1,196.377	1,123.499	526.248	1,931.618	5,886.256
Total Discards (mt)		0	4.174	0	0.376	1.619	6.170
2004							
Trips	1	3	12	9	7	1	33
Total Kept (mt)	24.948	89.132	327.945	378.682	342.689	0.102	1,163.498
Total Discards (mt)	0	0.907	12.774	0	2.287	0.519	16.487
Ratio discard/kept	0	0.01	0.039	0	0.007	5.088	0.014
Total Landings (mt)	1,527.714	5,646.571	6,664.912	8,184.790	3,987.020	0	26,011.007
Total Discards (mt)	0	57.459	259.609	0	26.608	0	343.676

Table C4. Estimates of kept weight (mt), discarded weight (mt) and discard ratios (discard/kept weight) of *Illex illecebrosus* sampled in the *Loligo* fishery, by observers from the NEFSC Observer Program, during 1995-2004. *Loligo* trips were defined as trips where *Loligo* landings were $\geq 25\%$, by weight, of the total trip landings. Estimates of total discards are based the product of discard ratios and reported *Loligo* landings, by month, for *Loligo* trips in the Weighout database.

	Nov	Dec	Jan	Feb	Mar	Apr	Total
1995							
Trips	0	1	1	1	0	0	3
Total Kept (mt)		1.195	0.513	2.971			4.679
Total Discard (mt)		0.000	0.000	0.002			0.002
Ratio discard/kept		0.000	0.000	0.001			0.000
Total Landings (mt)		537.991	981.273	1,407.113			2,926.377
Total Discards (mt)		0.000	0.000	0.947			1.251
1996							
Trips	1	1	1	2	1	0	6
Total Kept (mt)	3.009	0.335	0.760	11.952	10.972		27.028
Total Discard (mt)	1.100	0.000	0.000	0.068	0.069		1.237
Ratio discard/kept	0.366	0.000	0.000	0.006	0.006		0.046
Total Landings (mt)	347.441	306.178	2,077.435	1,933.899	1,462.509		6,127.462
Total Discards (mt)	127.014	0.000	0.000	11.003	9.197		280.438
1997							
Trips	0	0	1	2	1	1	5
Total Kept (mt)			2.220	23.071	8.137	12.084	45.512
Total Discard (mt)			0.318	0.206	0.278	0.687	1.489
Ratio discard/kept			0.143	0.009	0.034	0.057	0.033
Total Landings (mt)			602.383	1,192.511	752.883	735.620	3,283.397
Total Discards (mt)			86.287	10.648	25.722	41.821	107.422

Table C4. cont.

	Nov	Dec	Jan	Feb	Mar	Apr	Total
1998							
Trips	2	0	3	3	7	3	18
Total Kept (mt)	3.629		21.514	25.045	100.520	25.540	176.248
Total Discard (mt)	0.003		0.372	0.078	0.976	3.395	4.824
Ratio discard/kept	0.001		0.017	0.003	0.010	0.133	0.027
Total Landings (mt)	1,442.321		1,202.271	3,697.553	3,720.621	1,009.754	11,072.520
Total Discards (mt)	1.192		20.789	11.516	36.125	134.225	303.061
1999							
Trips	2	3	0	0	4	5	14
Total Kept (mt)	40.183	14.411			31.508	37.670	123.772
Total Discard (mt)	0.032	0.155			2.015	2.376	4.578
Ratio discard/kept	0.001	0.011			0.064	0.063	0.037
Total Landings (mt)	1,783.164	1,286.115			1,197.348	1,343.383	5,610.010
Total Discards (mt)	1.420	13.833			76.573	84.733	207.499
2000							
Trips	1	0	4	5	5	0	15
Total Kept (mt)	0.429		14.527	63.171	53.083		131.210
Total Discard (mt)	0.000		0.005	0.492	0.530		1.027
Ratio discard/kept	0.000		0.000	0.008	0.010		0.008
Total Landings (mt)	292.562		1,232.910	2,182.140	1,769.293		5,476.905
Total Discards (mt)	0.000		0.424	16.995	17.665		42.869

Table C4. cont.

	Nov	Dec	Jan	Feb	Mar	Apr	Total
2001							
Trips	2	1	1	4	5	1	14
Total Kept (mt)	21.32	11.05	2.864	29.828	61.793	23.918	150.773
Total Discard (mt)	0.227	0	0.906	1.789	0.402	0.228	3.552
Ratio discard/kept	0.011	0.000	0.316	0.060	0.007	0.010	0.024
Total Landings (mt)	1,908.420	1,691.437	519.057	850.685	1,557.575	979.096	7,506.270
Total Discards (mt)	20.319	0.000	164.199	51.022	10.133	9.333	176.837
2002							
Trips	0	0	1	3	0	3	7
Total Kept (mt)			20.117	24.937		15.183	60.237
Total Discard (mt)			0.15	1.026		0	1.176
Ratio discard/kept			0.007	0.041		0	0.020
Total Landings (mt)			1,272.791	1,338.373		111.488	2,722.652
Total Discards (mt)			9.490	55.066		0	53.154
2003							
Trips	4	2	0	0	0	2	8
Total Kept (mt)	9.734				18.673	13.290	41.697
Total Discard (mt)	0.412				0.027	2.702	3.141
Ratio discard/kept	0.042				0.001	0.203	0.075
Total Landings (mt)	348.863				2,050.161	1,602.186	4,001.210
Total Discards (mt)	14.766				2.964	325.742	343.472
2004							
Trips	10	21	3	15	0	5	54
Total Kept (mt)	7.188	207.010	12.416	156.471		265.424	648.509
Total Discard (mt)	2.750	3.050	2.693	23.371		12.537	44.401
Ratio discard/kept	0.383	0.015	0.217	0.149		0.047	0.068
Total Landings (mt)	1,651.820	2,585.834	979.853	1,355.578		2,892.108	9,465.194
Total Discards (mt)	631.957	38.099	212.528	202.473		136.605	1,221.662

Table C5. Summary of *Illex* discards (mt), by year and fishery, estimated from data collected by observers from the NEFSC Observer Program during 1995-2004.

Year	Percentage of landings sampled for <i>Illex</i> discards									Total <i>Illex</i> Landings (mt)	<i>Illex</i> Discards (% of <i>Illex</i> landings)
	<i>Illex</i> Fishery		<i>Loligo</i> Fishery		<i>Illex</i> Discards (mt)						
	<i>Illex</i> Landings (May-Oct, mt)	%	<i>Loligo</i> Landings (Nov-April, mt)	%	<i>Illex</i> Fishery	%	<i>Loligo</i> Fishery	%	Total		
1995	13,494	0.01%	6,702	0.07%	64	98	1	2	65	14,058	0.5%
1996	15,563	5.36%	7,070	0.38%	82	23	280	77	362	16,969	2.1%
1997	12,709	8.79%	6,484	0.69%	56	34	107	66	163	13,629	1.2%
1998	23,091	0.67%	12,755	1.38%	150	33	303	67	453	23,597	1.9%
1999	7,115	1.28%	7,811	1.59%	58	22	207	78	265	7,388	3.6%
2000	8,901	4.54%	5,810	2.25%	29	40	43	60	72	9,011	0.8%
2001	3,452	0.00%	7,506	2.01%	No data		177		177	4,009	4.4%
2002	2,342	0.00%	6,107	0.98%	No data		53		53	2,750	2.0%
2003	5,887	21.22%	8,804	0.47%	6	2	344	98	350	6,389	5.5%
2004	26,011	4.47%	10,350	6.27%	344	22	1,222	78	1,566	26,087	6.0%

Table C6. Standardized, stratified mean catch per tow (delta-transformed) in numbers/tow, and kg/tow of *Illex illecebrosus*, pre-recruits (≤ 10 cm) and recruits (≥ 11 cm), caught during autumn research bottom trawl surveys in offshore strata 1-40 and 61-76 from Cape Hatteras to the Gulf of Maine during 1967-2004.

Year	All sizes (no./tow)	CV (%)	All sizes (kg/tow)	CV (%)	Individual Mean Weight (g)	Pre-recruits (no./tow)	Recruits (no./tow)
1967	1.57	17	0.242	17	147	0.04	1.53
1968	1.64	21	0.307	17	186	0.10	1.54
1969	0.59	23	0.073	26	121	0.09	0.50
1970	2.26	21	0.268	15	110	0.85	1.41
1971	1.68	12	0.337	14	206	0.20	1.48
1972	2.19	25	0.292	15	123	0.48	1.71
1973	1.47	24	0.353	25	242	0.04	1.43
1974	2.82	40	0.392	30	145	1.20	1.62
1975	8.74	36	1.417	18	143	3.98	4.76
1976	20.55	16	7.018	19	317	0.42	20.13
1977	12.62	18	3.740	18	299	0.72	11.90
1978	19.25	21	4.529	26	219	3.29	15.96
1979	19.42	11	6.053	11	305	1.31	18.11
1980	13.81	15	3.285	18	238	0.43	13.38
1981	27.10	32	9.340	40	327	0.22	26.88
1982	3.94	15	0.602	13	155	0.71	3.23
1983	1.73	14	0.233	13	134	0.16	1.57
1984	4.54	17	0.519	19	113	0.32	4.22
1985	2.38	17	0.355	18	147	0.19	2.19
1986	2.10	15	0.257	17	119	0.26	1.84
1987	15.83	31	1.527	29	92	0.84	14.99
1988	23.22	25	2.997	24	121	0.41	22.81
1989	22.43	45	3.307	57	118	1.05	21.38
1990	16.61	12	2.401	13	141	0.61	16.00
1991	5.21	17	0.691	18	129	0.22	4.99
1992	8.24	15	0.804	16	98	1.79	6.45
1993	10.42	19	1.595	20	159	0.15	10.27
1994	6.83	24	0.860	25	128	0.22	6.61
1995	8.01	30	0.700	39	84	0.82	7.19
1996	10.76	22	0.926	19	87	0.60	10.16
1997	5.83	24	0.521	17	89	0.74	5.09
1998	14.60	51	1.400	50	94	1.18	13.42
1999	1.39	16	0.192	17	136	0.15	1.24
2000	7.41	28	0.706	22	94	0.95	6.46
2001	4.49	27	0.323	23	72	0.46	4.03
2002	6.36	20	0.444	19	70	1.01	5.35
2003	28.46	61	1.946	67	69	3.12	25.34
2004	5.06	24	0.412	22	82	1.09	3.97
Average							
1967-1981	9.05	22	2.510	21	209	0.89	8.16
1982-2003	9.58	25	1.06	25	111	0.73	8.86
1967-2003	9.36	24	1.65	23	151	0.79	8.57
1999-2003	9.62	30	0.72	29	88	1.14	8.48

Table C7. Summary of data from Vessel Trip Reports submitted by fishermen participating in the *Illex illecebrosus* fishery during 2003 and 2004. FT represents freezer trawlers and RSW represents refrigerated seawater system trawlers.

	2003			2004		
	FT	RSW	Total	FT	RSW	Total
N vessels	3	11	14	12	16	28
N trips	32	80	112	92	355	447
Average trip duration (days absent from port)	8.2	2.8	4.4	6.5	1.8	2.8
Average nominal effort (days fished) per trip	2.1	0.8	1.2	1.1	0.5	0.6
Average landings (mt)	152	17	55	122	34	52
Average nominal LPUE (mt/df)	71	22	48	111	76	89
Total fishery landings (mt)	4,859	1,337	6,195	12,174	11,198	23,372
Proportion of total annual landings	0.78	0.22		0.52	0.48	
Total nominal effort (days fished)	69	61	130	101	161	262
Proportion of total annual effort	0.53	0.47		0.39	0.61	
Duration of fishing season (weeks) ¹			23			18
Timing of fishing season			weeks 24-46			weeks 21-38

¹ Fishery closed on 9/21/2004 because quota of 24,000 mt was landed

Table C8. Results of a General Linear Model with log-transformed landings per unit effort from the 2003 U.S. *Illex illecebrosus* fishery as the dependent variable and week of year, vessel type (freezer or RSW trawler), and quarter-degree square fishing area as class effects in the model.

Source	DF	Sum of Squares	Mean Square	F	Pr > F
Model	28	64.92159721	2.31862847	3.35	< 0.0001
Error	50	34.60964687	0.69219294		
Corrected Total	78	99.53124408			
R-Square	CV	Root MSE	ln (lpuemt) Mean		
0.652274	25.36757	0.831981	3.279705		
Source	DF	Type I SS	Mean Square	F	Pr > F
wkofyr	21	43.71807976	2.08181332	3.01	0.0007
vessel type	1	16.85165507	16.85165507	24.35	<.0001
quarter-degree square	6	4.35186239	0.7253104	1.05	0.4062
Source	DF	Type III SS	Mean Square	F	Pr > F
wkofyr	21	28.38454289	1.3516449	1.95	0.0271
vessel type	1	16.32903841	16.32903841	23.59	<.0001
quarter-degree square	6	4.35186239	0.7253104	1.05	0.4062
Parameter		Estimate	Standard Error	t Value	Pr > t
Intercept		2.892167156	0.65598996	4.41	<.0001
wkofyr	23	-0.83677222	1.09519873	-0.76	0.4484
	26	0.025684254	0.85545884	0.03	0.9762
	27	-0.556877471	0.80031553	-0.70	0.4898
	28	0.727561846	0.7656278	0.95	0.3465
	29	-1.057333371	0.80031553	-1.32	0.1925
	30	0.050102596	0.8073132	0.06	0.9508
	31	0.820210337	0.87588503	0.94	0.3535
	32	0.174250298	0.79740912	0.22	0.8279
	33	-0.810892382	0.71768494	-1.13	0.2639
	34	0.326811416	0.85266844	0.38	0.7031
	35	0.473101326	0.74953597	0.63	0.5308
	36	-0.192868857	0.72695638	-0.27	0.7919
	37	-0.448380259	0.89406911	-0.50	0.6182
	38	0.773904369	0.74364221	1.04	0.3030
	39	0.74920603	0.74830111	1.00	0.3215
	40	0.564620776	0.71213424	0.79	0.4316

	41	0.303483041	0.73487454	0.41	0.6814
	42	-0.252719536	0.7925821	-0.32	0.7512
	44	0.06387861	1.03822267	0.06	0.9512
	45	-0.87454083	1.03822267	-0.84	0.4036
	46	-2.196469961	1.09814748	-2.00	0.0509
	924	0			
vessel type	freezer	1.38042707	0.28421484	4.86	<.0001
	90	0			
quarter-degree square	35744	-0.251695345	0.48585275	-0.52	0.6067
	36744	-0.051855303	0.39807988	-0.13	0.8969
	37741	-0.554991953	0.47689578	-1.16	0.2500
	38731	-0.248242504	0.44571473	-0.56	0.5800
	38732	-0.361044568	0.33103193	-1.09	0.2806
	38734	0.673924219	0.51879469	1.30	0.1999
	936742	0			

Table C9. Results of a General Linear Model with log-transformed landings per unit effort from the 2004 U.S. *Illex illecebrosus* fishery as the dependent variable and week of year, vessel type (freezer or RSW trawler), and quarter-degree square fishing area as class effects in the model.

Source	DF	Sum of Squares	Mean Square	F	Pr > F
Model	30	31	56.7928322	1.8320268	< 0.0001
Error	340	368	167.8628528	0.4561491	
Corrected Total	370	399	224.655685		
R-Square	Coeff Var	Root MSE	lnlpuemt Mean		
0.252799	15.43396	0.675388	4.375987		
Source	DF	Type I SS	Mean Square	F	Pr > F
wkofyr	19	24.77420331	1.30390544	2.86	<.0001
vessel type	1	12.40259859	12.40259859	27.19	<.0001
quarter-degree square	11	19.61603029	1.78327548	3.91	<.0001
Source	DF	Type III SS	Mean Square	F	Pr > F
wkofyr	19	30.60929990	1.61101578	3.53	<.0001
vessel type	1	17.81584700	17.81584700	39.06	<.0001
quarter-degree square	11	19.61603029	1.78327548	3.91	<.0001
Parameter		Estimate	Standard Error	t Value	Pr > t
Intercept		4.260992	0.232047	18.36	<.0001
wkofyr	20	0.280698	0.508075	0.55	0.581
	21	-0.395540	0.243112	-1.63	0.1046
	22	0.482445	0.254427	1.9	0.0587
	23	0.346848	0.238090	1.46	0.146
	25	-0.244626	0.211317	-1.16	0.2478
	26	0.016649	0.207027	0.08	0.9359
	27	-0.015857	0.217309	-0.07	0.9419
	28	0.340708	0.203401	1.68	0.0948
	29	-0.161689	0.210484	-0.77	0.4429
	30	-0.000075	0.220173	0.00	0.9997
	31	0.157004	0.238182	0.66	0.5102
	32	0.141091	0.228924	0.62	0.5381
	33	0.320713	0.206790	1.55	0.1218
	34	0.688085	0.215205	3.20	0.0015
	35	0.551480	0.199831	2.76	0.0061
	36	0.023374	0.213164	0.11	0.9127
	37	0.188770	0.240686	0.78	0.4334

	38	0.070158	0.236524	0.30	0.7669
	39	-0.971570	0.454831	-2.14	0.0333
	924	0			
vessel type	freezer	0.634100	0.101463	6.25	<.0001
	90	0			
quarter-degree square	37734	0.037820	0.372147	0.10	0.9191
	37741	-0.098423	0.277586	-0.35	0.7231
	37742	-0.804485	0.276812	-2.91	0.0039
	37743	0.216598	0.298521	0.73	0.4686
	38724	0.101493	0.210326	0.48	0.6297
	38731	-0.298963	0.183363	-1.63	0.1039
	38732	-0.077336	0.173498	-0.45	0.6561
	38733	-0.031082	0.188733	-0.16	0.8693
	39693	0.858187	0.701742	1.22	0.2222
	39721	-1.453390	0.236918	-6.13	<.0001
	39722	-0.806836	0.381026	-2.12	0.0349
	999999	0			

Table C10. Probability values ($\alpha = 0.05$) from General Linear Models used to standardize catch rates in the *Illex illecebrosus* fishery during 2003 and 2004. Vessel types were characterized as freezer trawler (FT) or refrigerated seawater system (RSW) trawler.

Effect	2003		2004					
					RSW		FT	
Week of year	0.0271	0.1230	0.0001	0.0001	0.0001	0.0001	0.0001	0.0025
Quarter-degree square	0.4062	0.9807	0.0001	0.0737	0.0588	0.0177	0.7251	0.0001
Vessel type	0.0001		0.0001					
Hull Number		0.0008		0.0001	0.0001		0.0001	
Model	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
R ²	0.65	0.75	0.25	0.67	0.65	0.20	0.72	0.28
df	28	38	31	52	45	25	47	24

Table C11. Status of research recommendations from the previous *Illex* stock assessment (SARC 37).

Research Recommendation	Status
Continue model development, with the objective of producing sound statistical models for stock assessment purposes	All three models presented at SARC 37 were improved upon and tested further. These models require seasonal age and maturity data before further model testing can be done.
Consider the development of "operating models" which can be used to test the effectiveness of alternative management strategies	This research recommendation cannot be accomplished until a reliable stock assessment model is available.
Evaluate the relationship between growth rates and sea temperature to define possible changes in stock productivity associated with environmental conditions.	Not completed. Requires a funding source for the collection and analysis of growth rate data.
Define biological indicators of low or high productivity regimes.	In progress. There is a relationship between <i>Illex</i> body size, autumn survey relative abundance indices, and bottom temperature anomalies on the US Shelf. However, further investigation of these relationships is needed.
Evaluate seasonal and latitudinal clines in growth rates.	Not completed. Requires a funding source for the collection and analysis of growth rate data.
Evaluate and design cooperative research programs with commercial vessels for sampling of size, weight and possible age of <i>Illex</i> during the fishing season	Completed. Length and weight data from the fishery are collected by the <i>Illex</i> processors/dealers and sent to the NEFSC for use in the assessments.
Continue with cooperative ventures for pre-season survey to obtain possible indices of upcoming stock abundance and productivity.	A pre-season <i>Illex</i> survey was conducted using commercial vessels in 2000 with funds from an external grant and these data were used in the assessments (SARC 37 and current). External funding is needed to conduct a second <i>Illex</i> pre-season survey to assess the inter-annual variability of the data.
Evaluate catch rates by vessel by using VTR and Weighout databases to improve procedures for standardization of nominal LPUE.	Completed during the current assessment.

ILLEX FIGURES

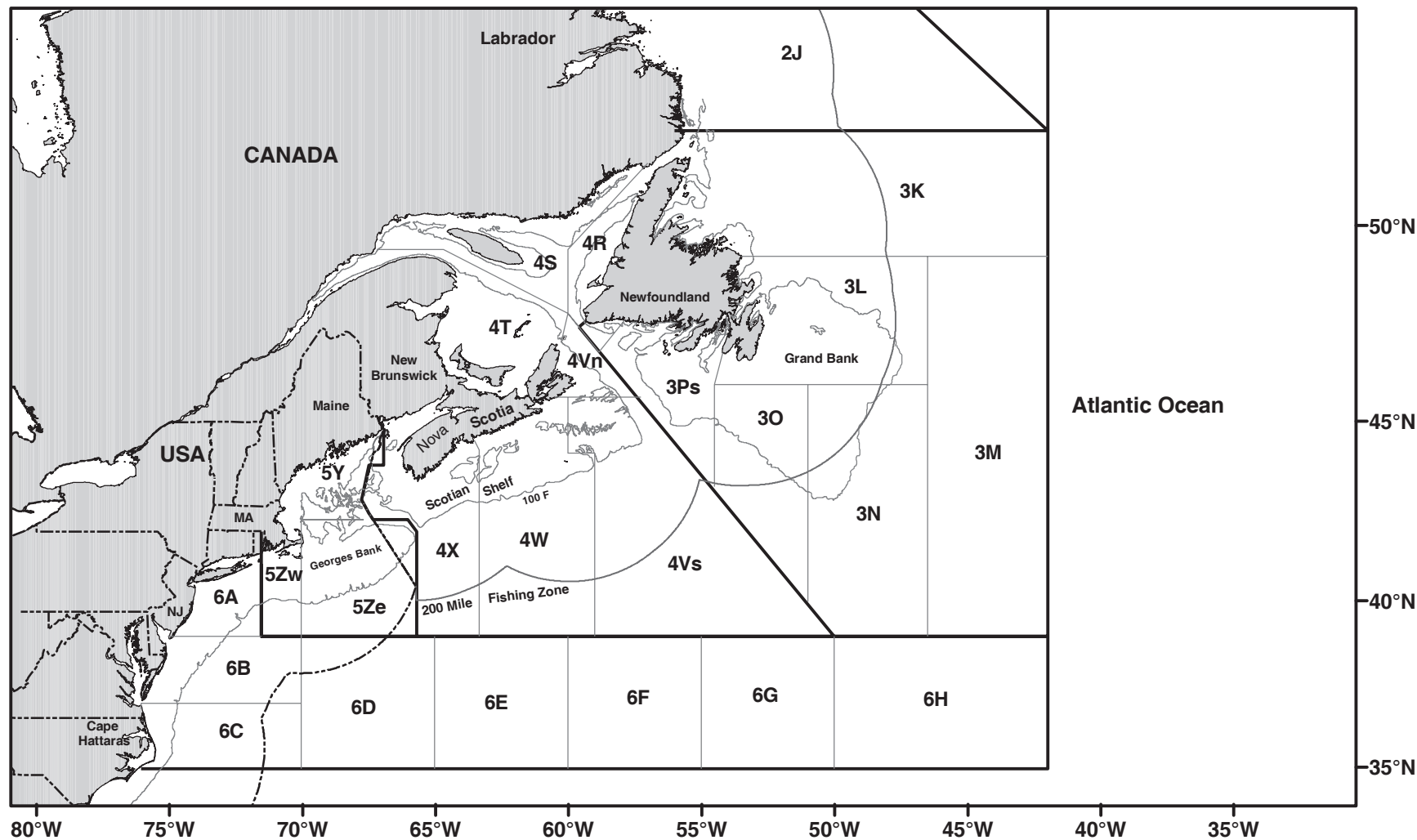


Figure C1. Catch reporting areas of the Northwest Atlantic Fisheries Organization (NAFO) for Subareas 3-6.

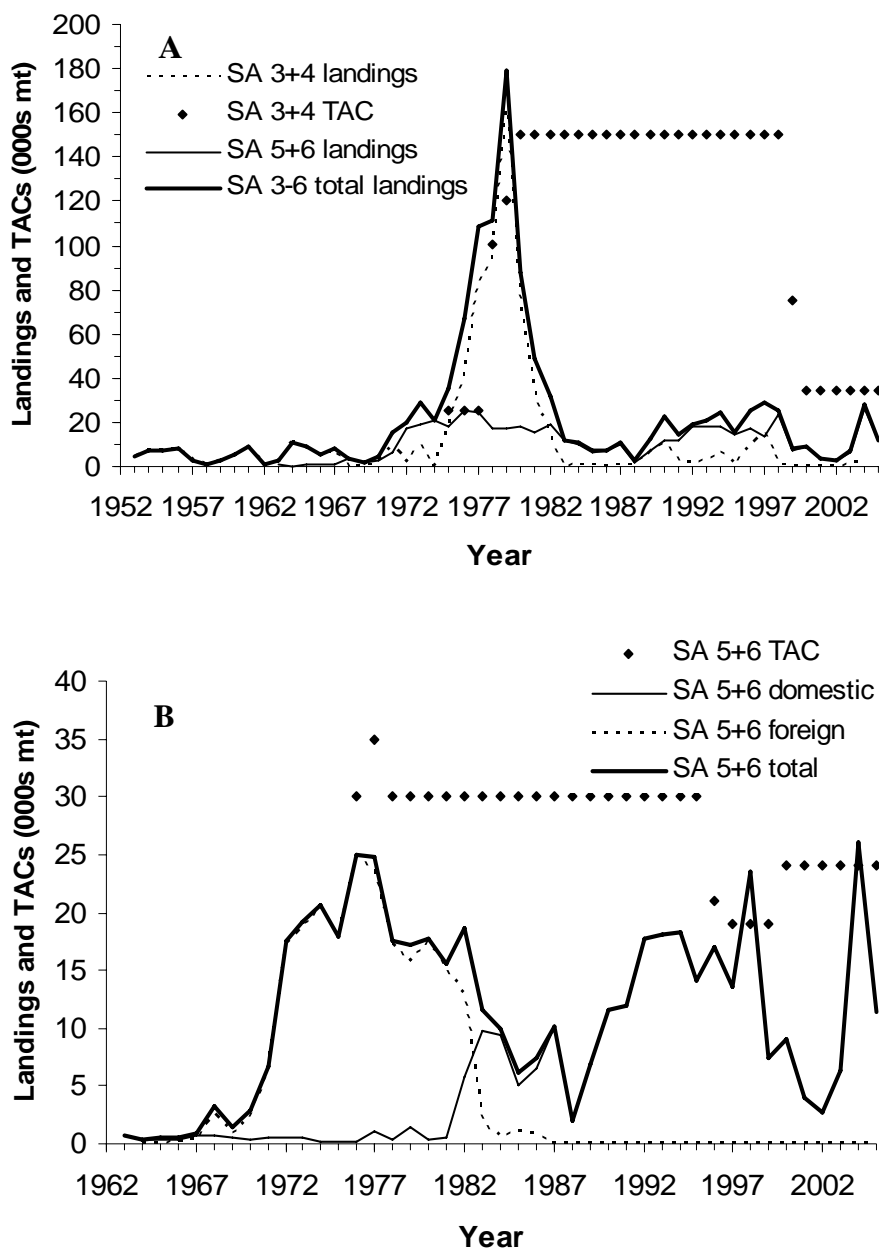


Figure C2. Total landings of *Illex illecebrosus* in (A) NAFO Subareas 3-6 and (B) in the US EEZ (NAFO Subareas 5+6), with respect to annual TACs, during 1963-2005.

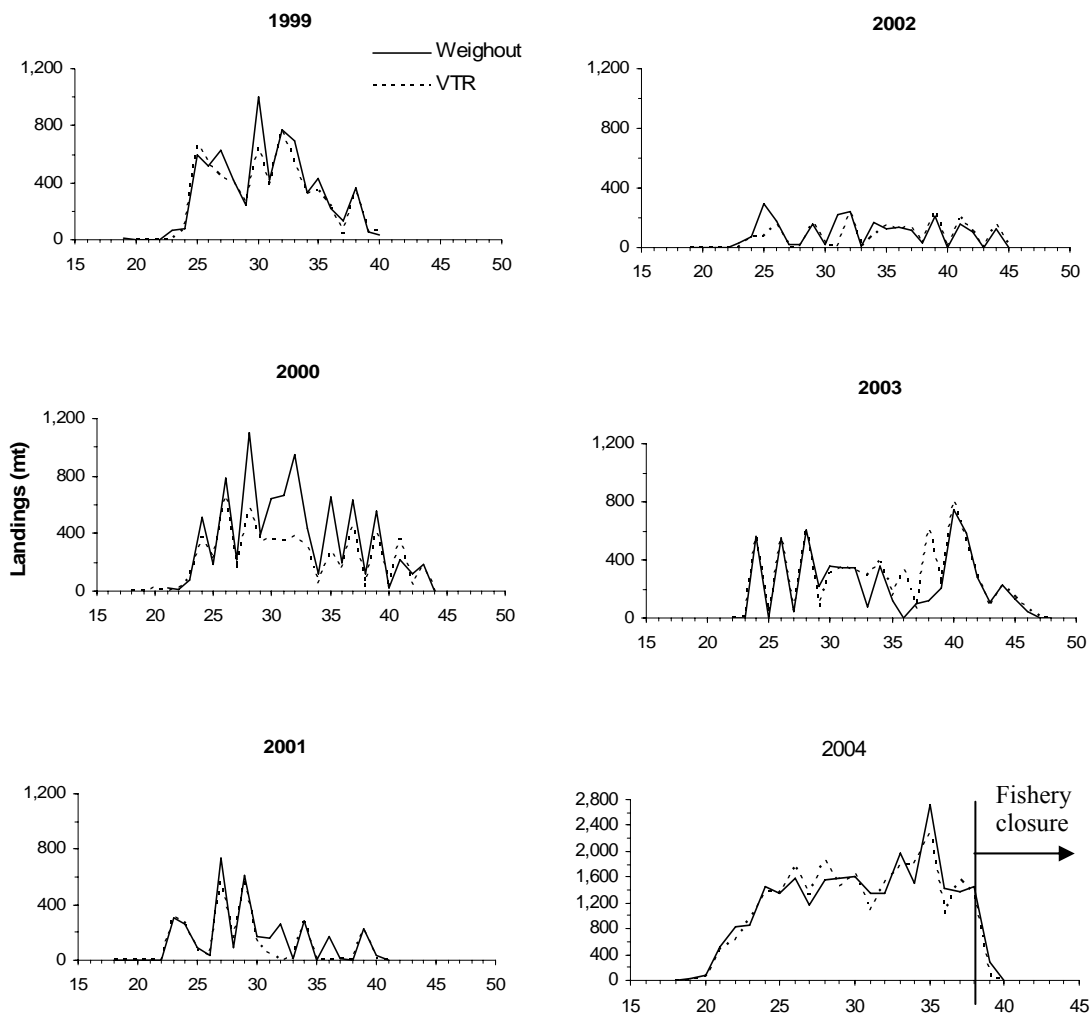


Figure C3. Trends in weekly *Illex illecebrosus* landings from the Weighout database versus the Vessel Trip Report database during 1999-2004.

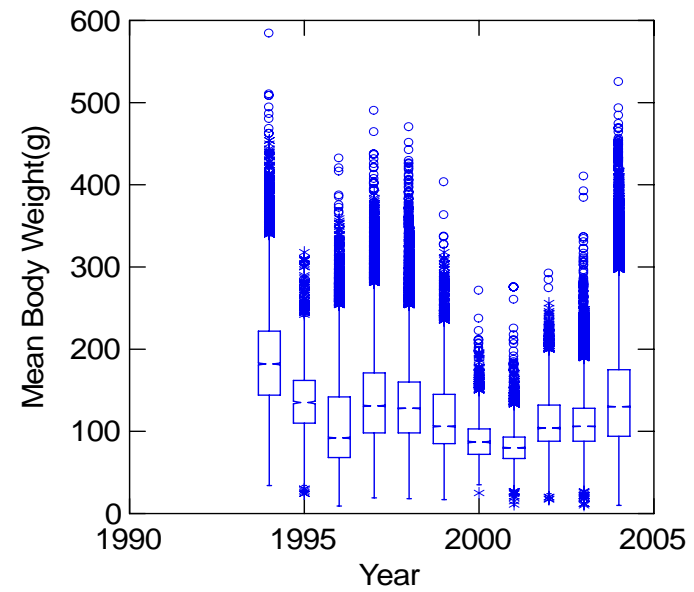
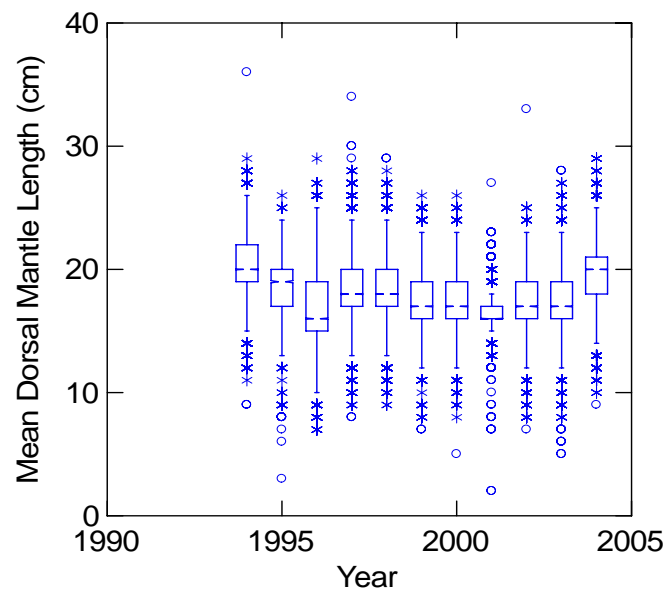


Figure C4. Annual trends in the dorsal mantle length (cm) and body weight (g) of *Illex illecebrosus* landed during 1994-2004. The boxes represent the boundaries of the interquartile range and the notch within the box represents the median.

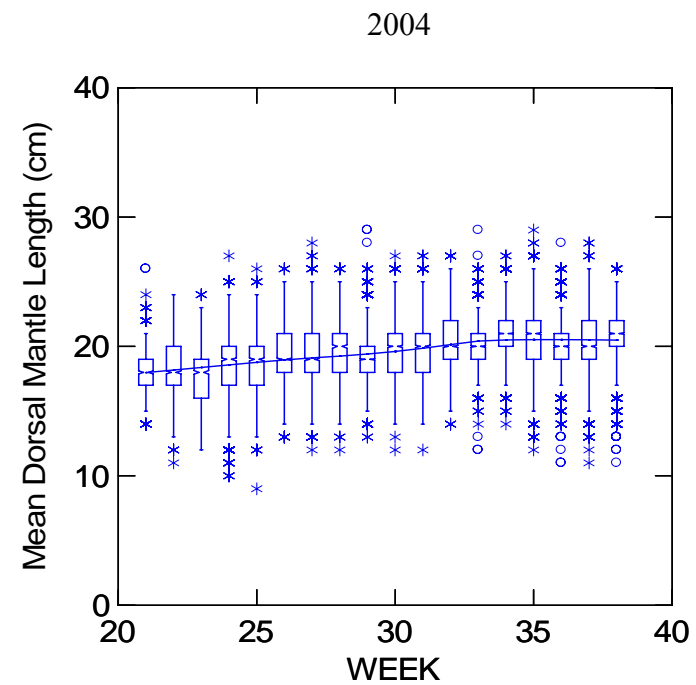
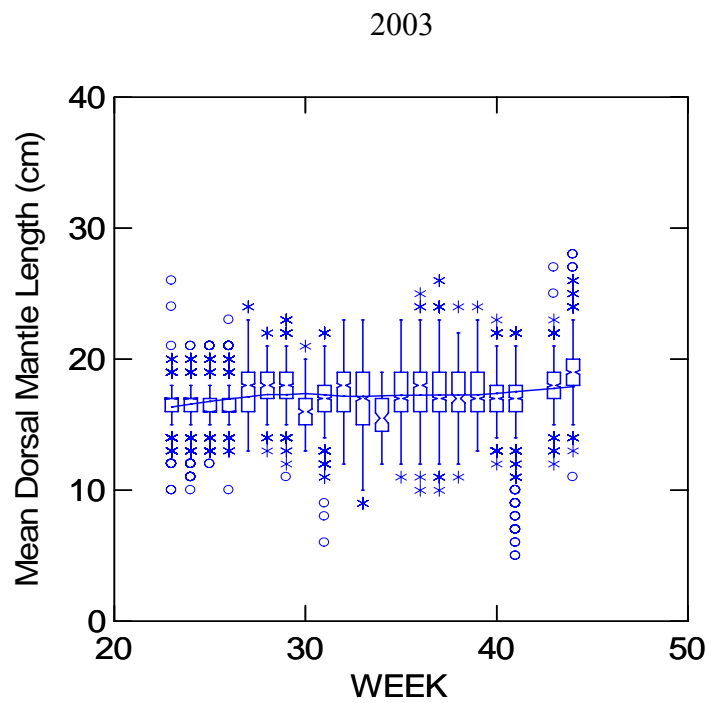


Figure C5. Weekly trends in the dorsal mantle length (cm) of *Illex illecebrosus* landings during 2003 and 2004. The solid line represents a loess smooth of the observed values with a tension factor of 0.5.

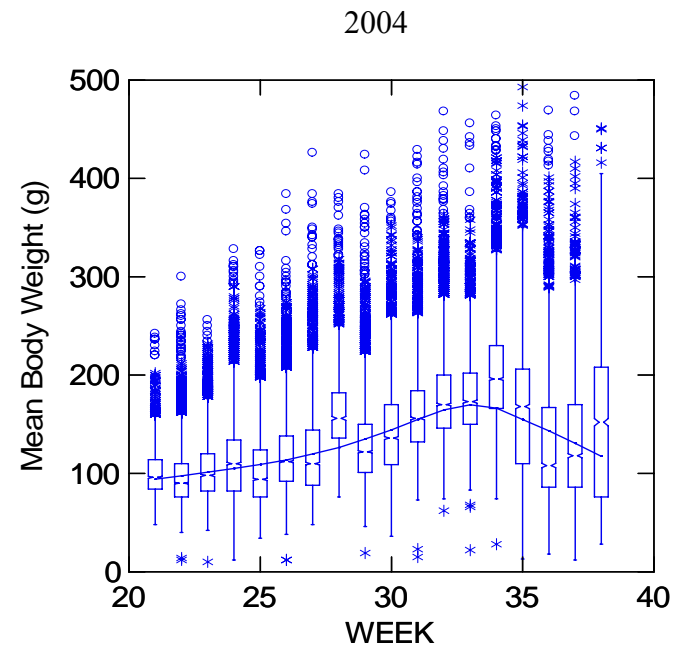
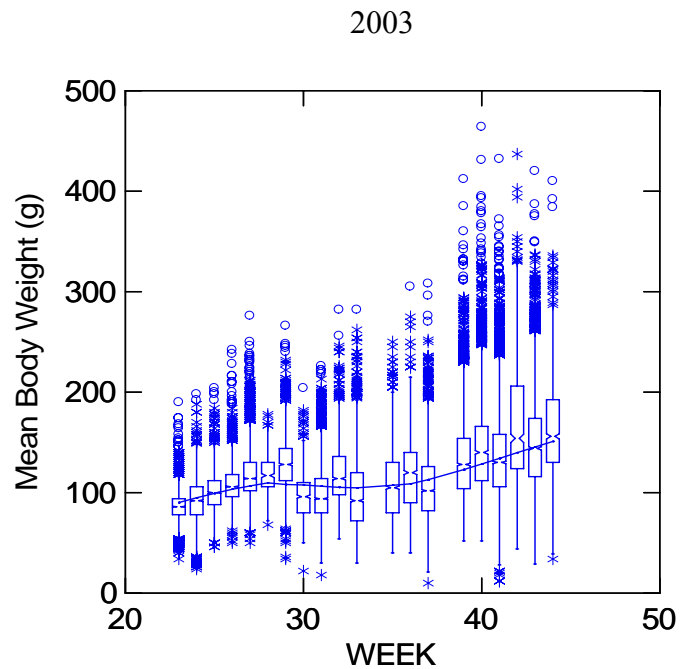


Figure C6. Weekly trends in the body weight (g) of *Illex illecebrosus* landings during 2003 and 2004. The solid line represents a loess smooth of the observed values with a tension factor of 0.5.

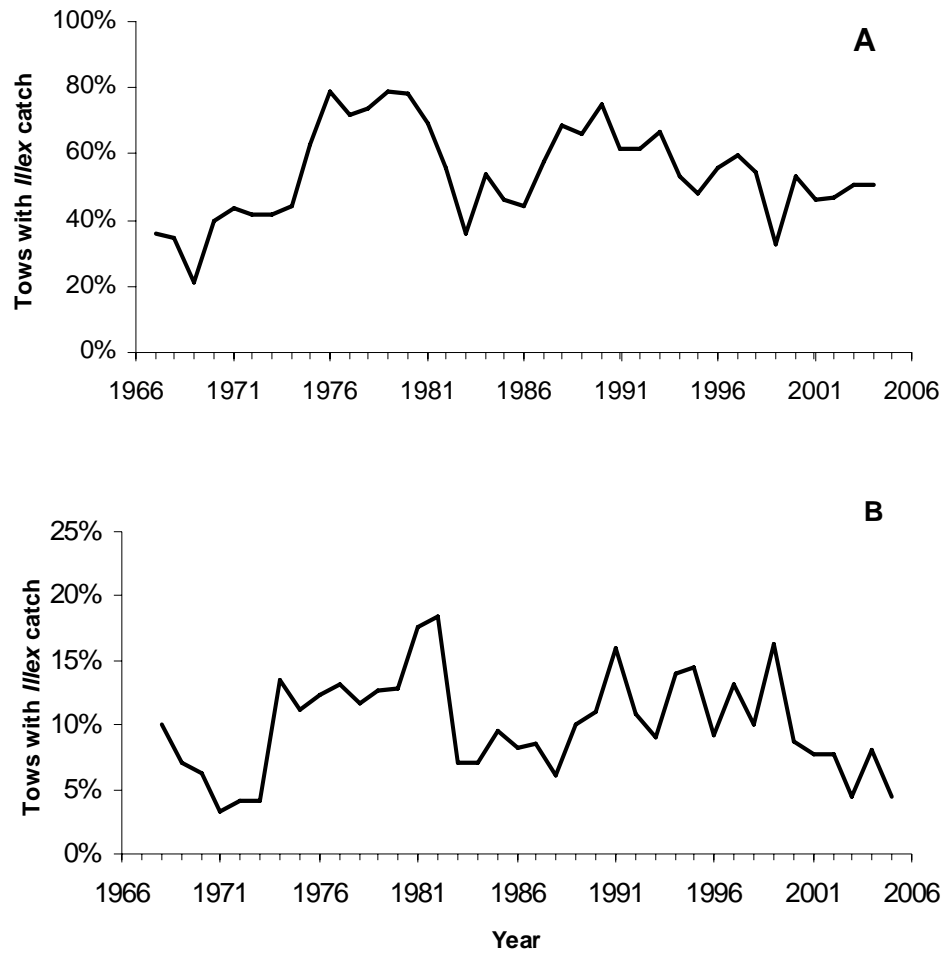


Figure C7. Annual trends in the percentage of tows with *Illex* catch, in offshore strata sampled during the (A) NEFSC autumn (1967-2004) and (B) spring (1968-2005) research bottom trawl surveys.

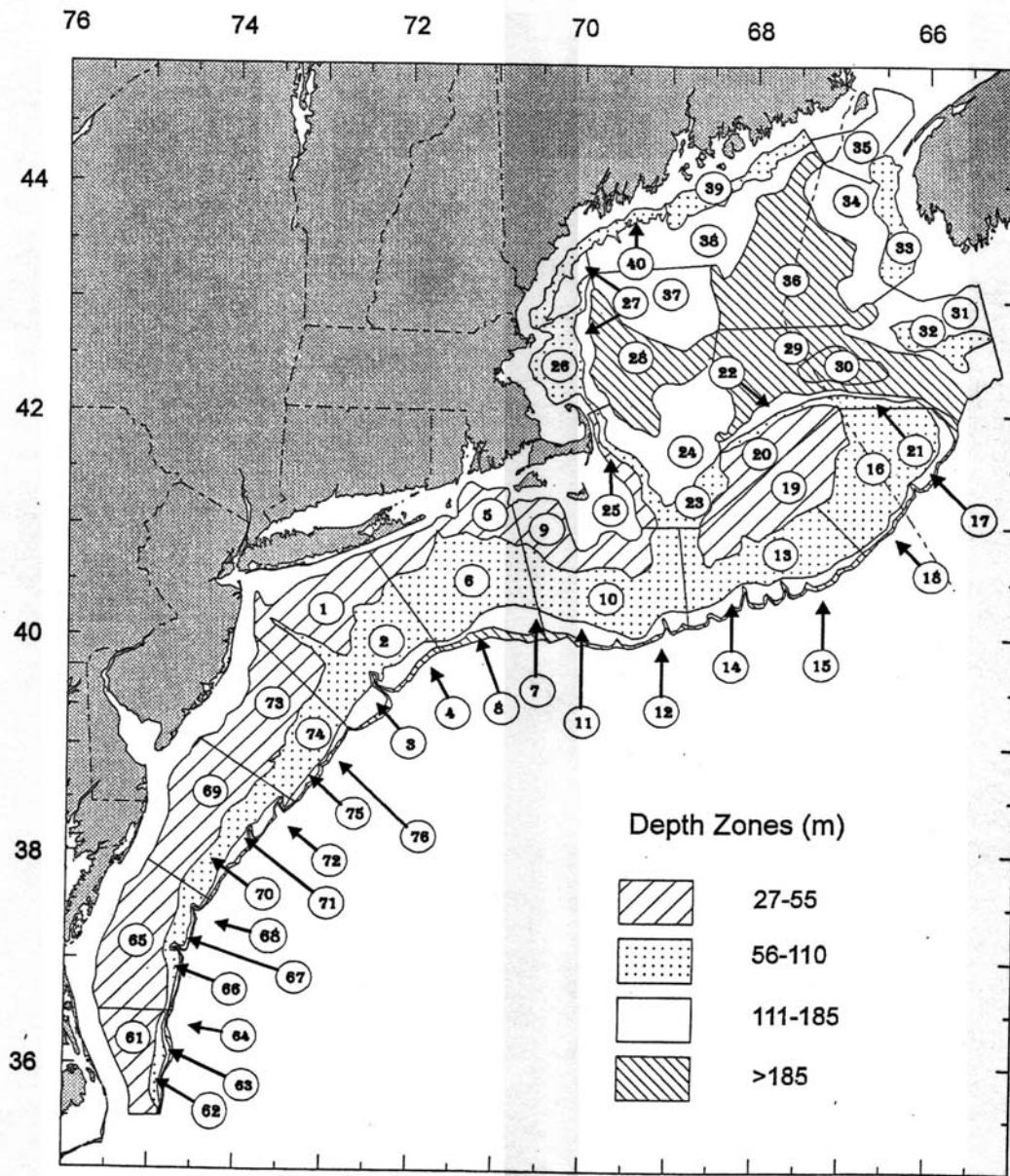


Figure C8. Offshore depth strata sampled during Northeast Fisheries Science Center bottom trawl research surveys.

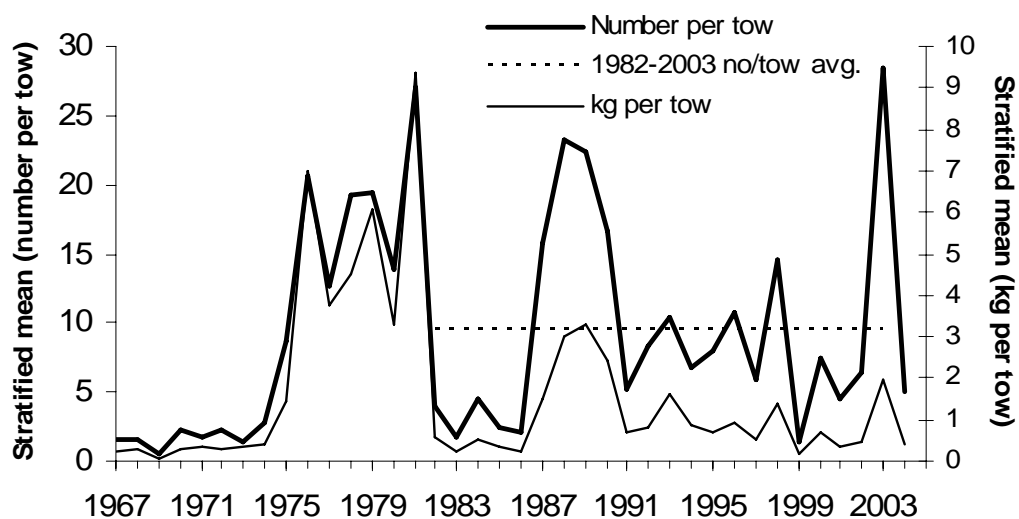


Figure C9. Trends in *Illex illecebrosus* relative abundance (stratified mean number tow) and biomass (stratified mean kg per tow) indices based on data from NEFSC autumn bottom trawl surveys conducted on the USA shelf during 1967-2004.

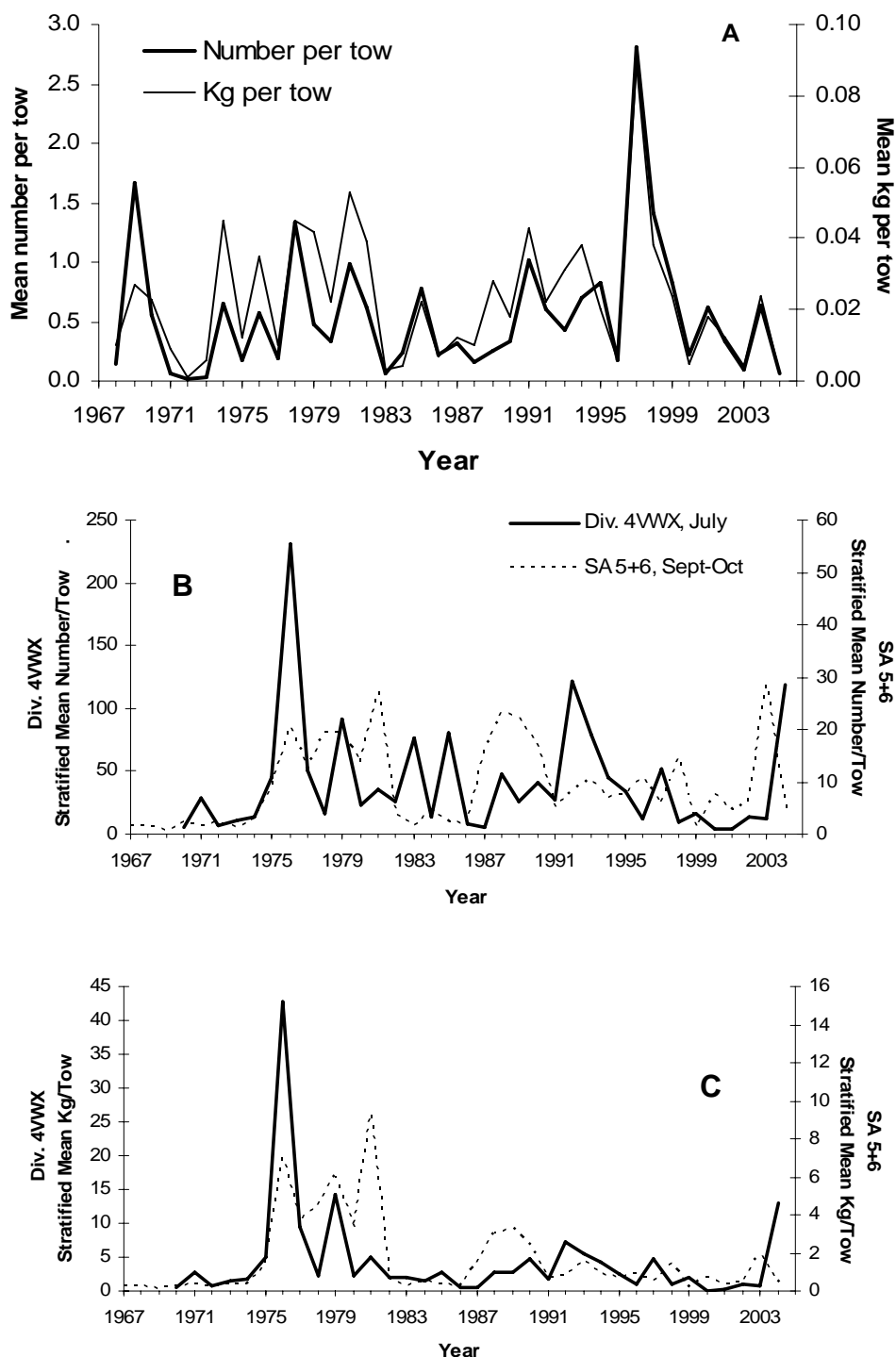


Figure C10. Trends in *Illex illecebrosus* relative abundance (stratified mean number per tow) and biomass (stratified mean kg per tow) based on bottom trawl surveys of (A) the USA shelf during March and (B and C) the USA shelf in September/October and the Scotian Shelf in July. Scotian Shelf survey indices could not be standardized for gear and vessel changes that occurred in 1982, 1983 and 2004.

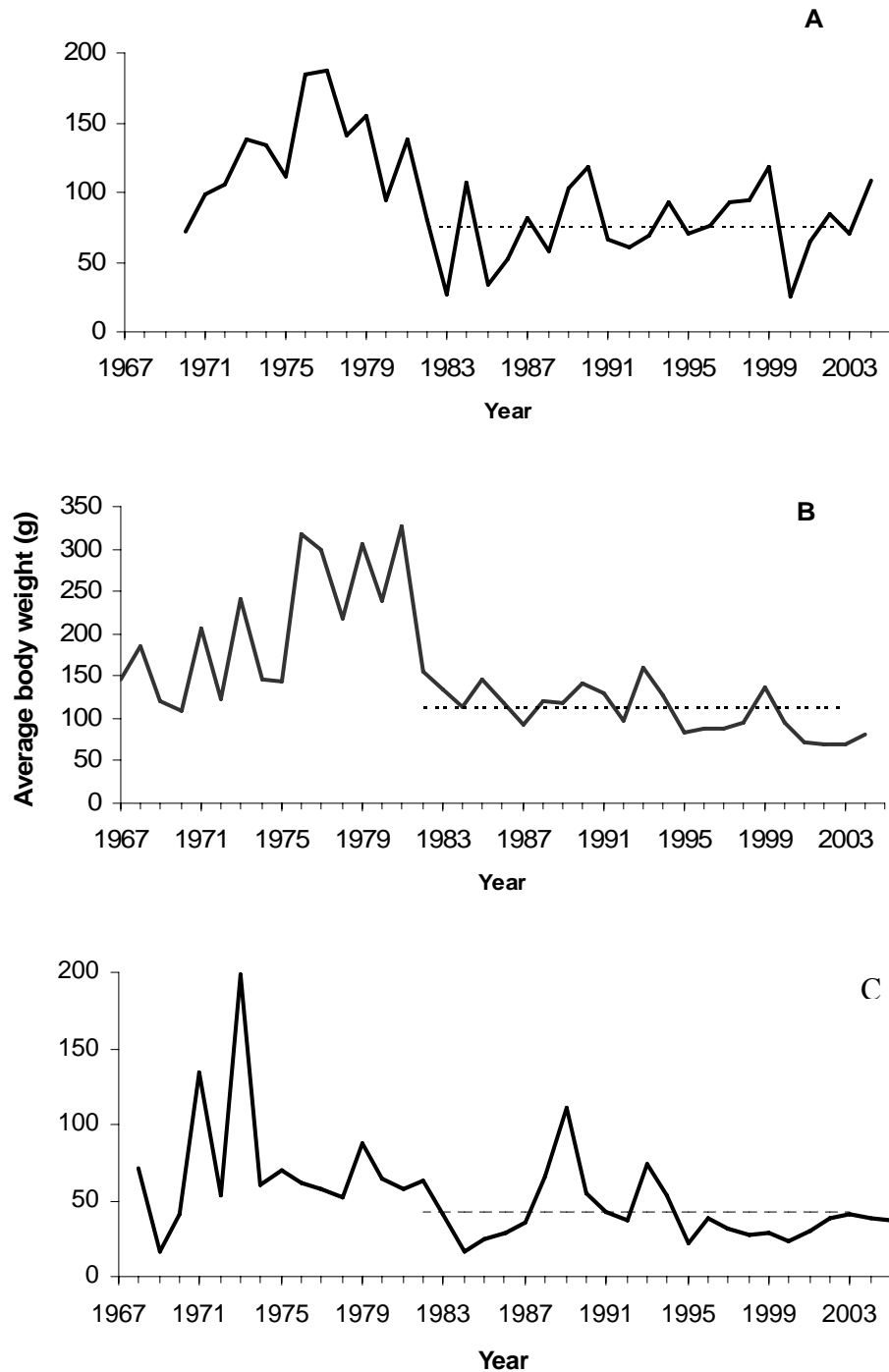


Figure C11. Trends in average body weight (g) of *Illex illecebrosus* caught during (A) Canadian research bottom trawl surveys conducted in July on the Scotian Shelf (1970-2004) and NEFSC (B) autumn (1967-2004) and (C) spring (1968-2005) research bottom trawl surveys of the U. S. Shelf. The dashed line represents the 1982-2003 average body weight.

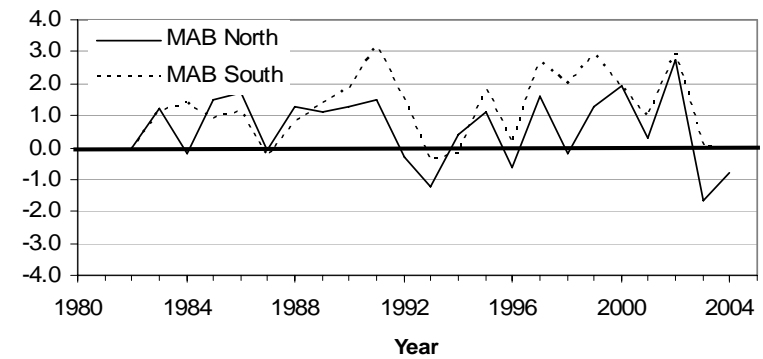
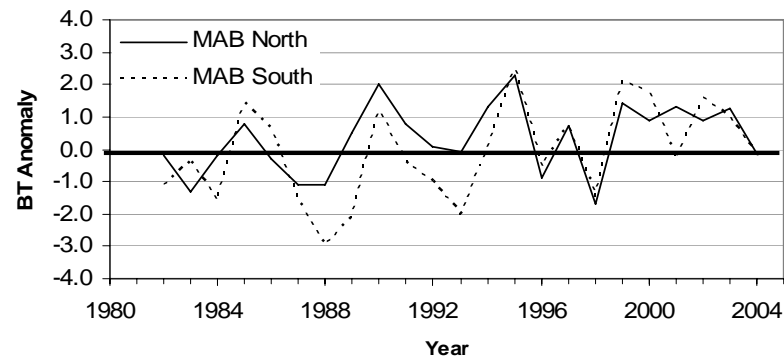
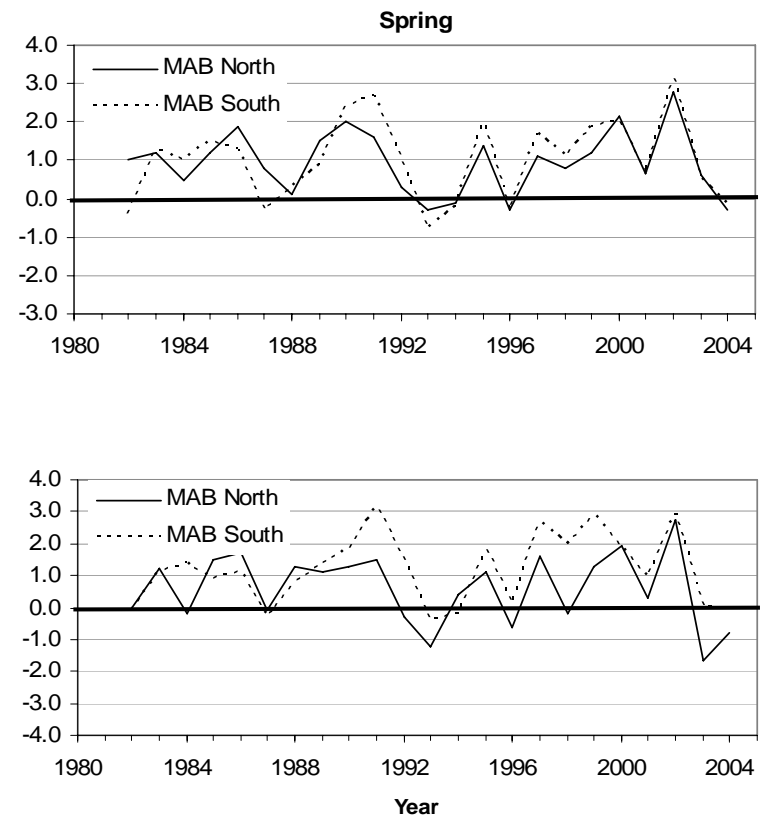
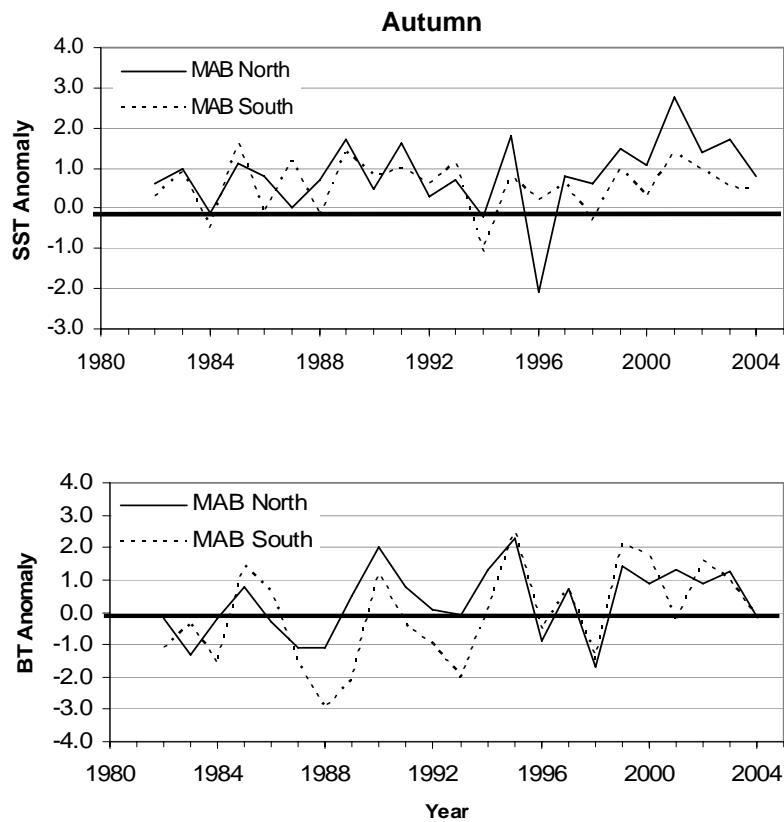


Figure C12. Sea surface temperature and bottom temperature anomalies in the Mid-Atlantic Bight, north versus south, during NEFSC autumn and spring research bottom trawl surveys, 1982-2004. The reference period is 1977-1987.

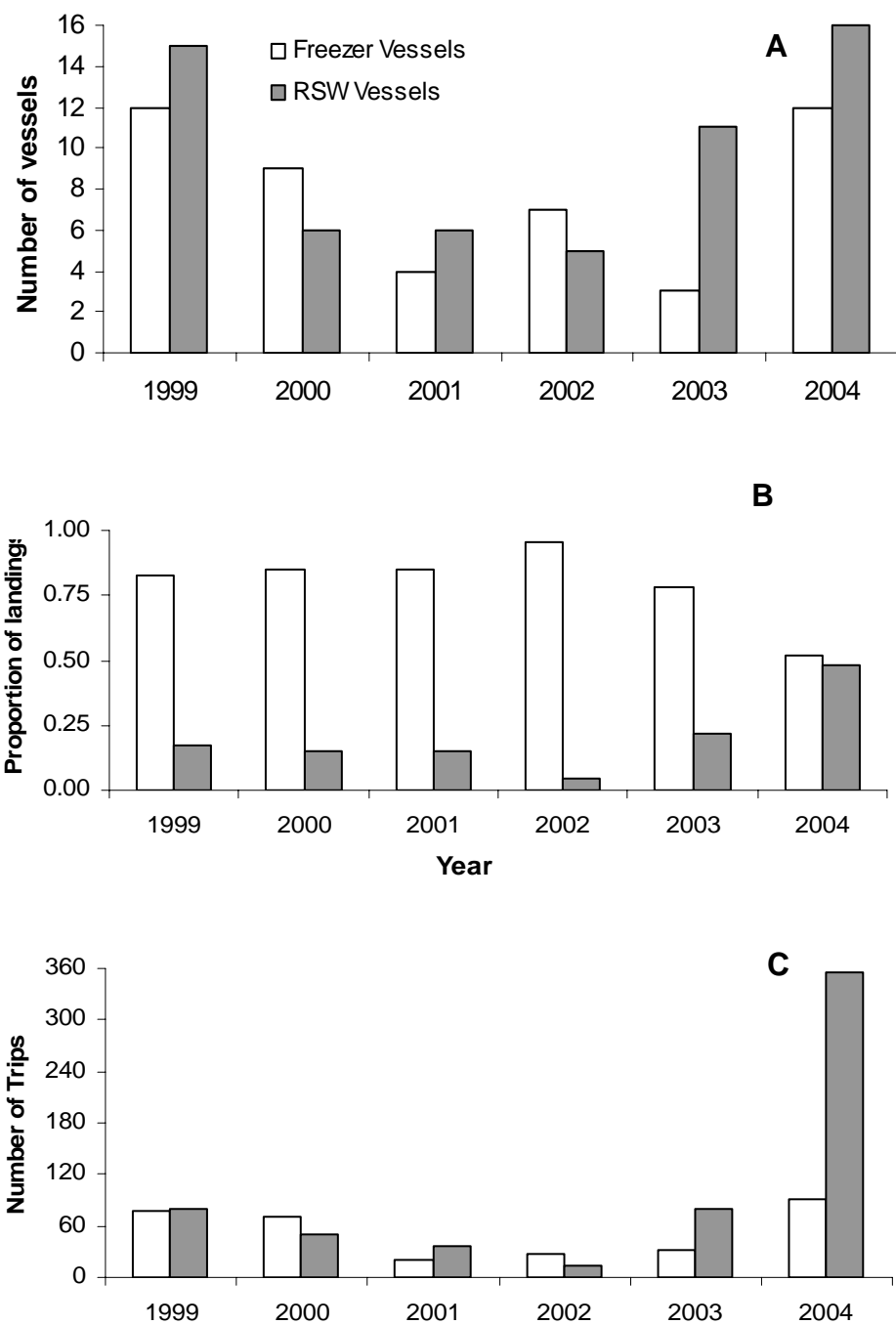


Figure C13. Number of (A) vessels, (B) proportion of annual landings and (C) number of trips, by fleet sector, in the directed fishery during 1999-2004.

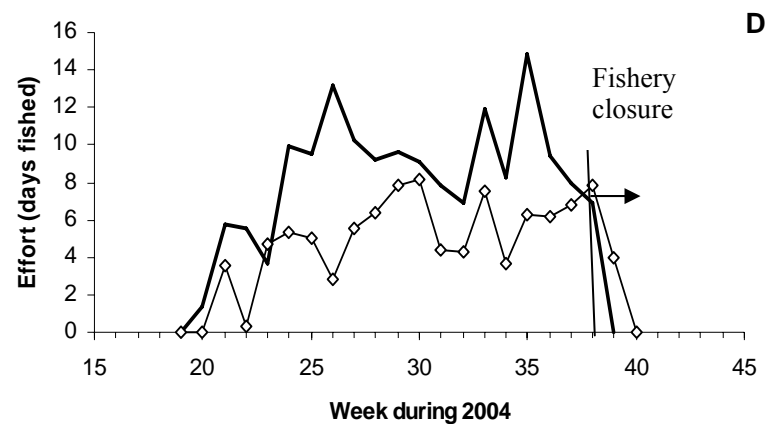
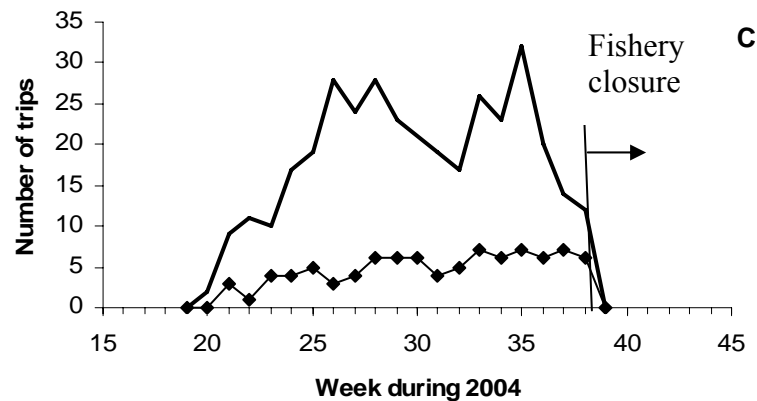
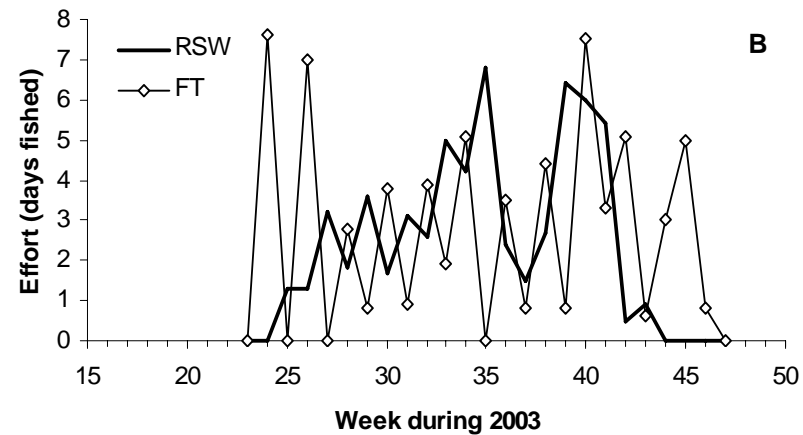
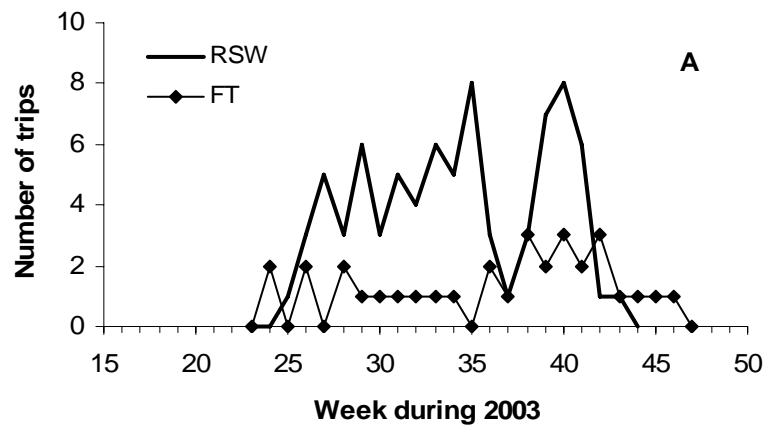


Figure C14. Number of fishing trips and nominal effort (days fished) for freezer trawlers (FT) and refrigerated seawater system (RSW) trawlers, by week, during 2003 (A and B) and 2004 (C and D).

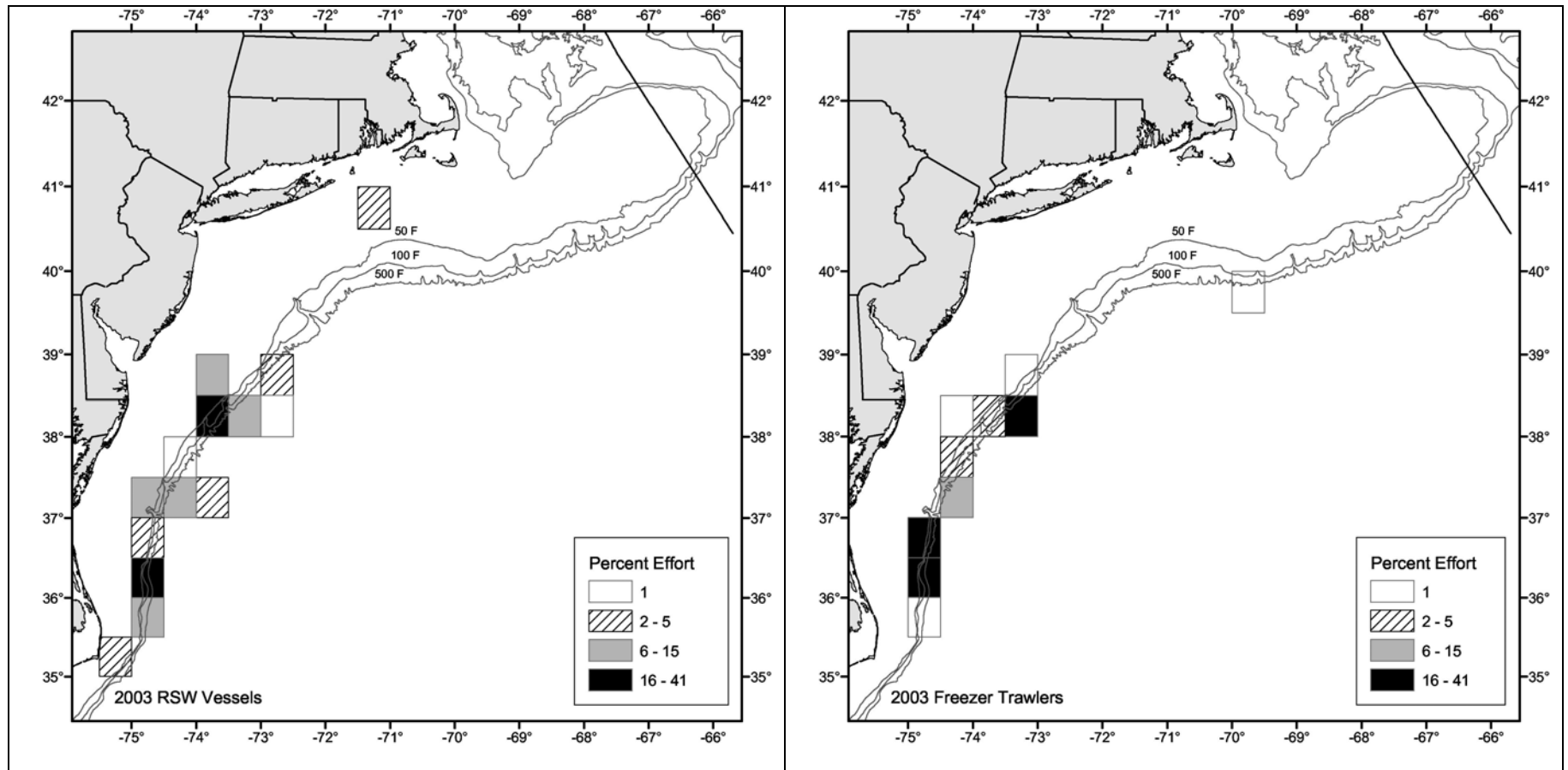


Figure C15. Percentage of nominal annual effort, by quarter-degree square, for refrigerated seawater system (RSW) trawlers and freezer trawlers participating in the *Illex illecebrosus* fishery during 2003.

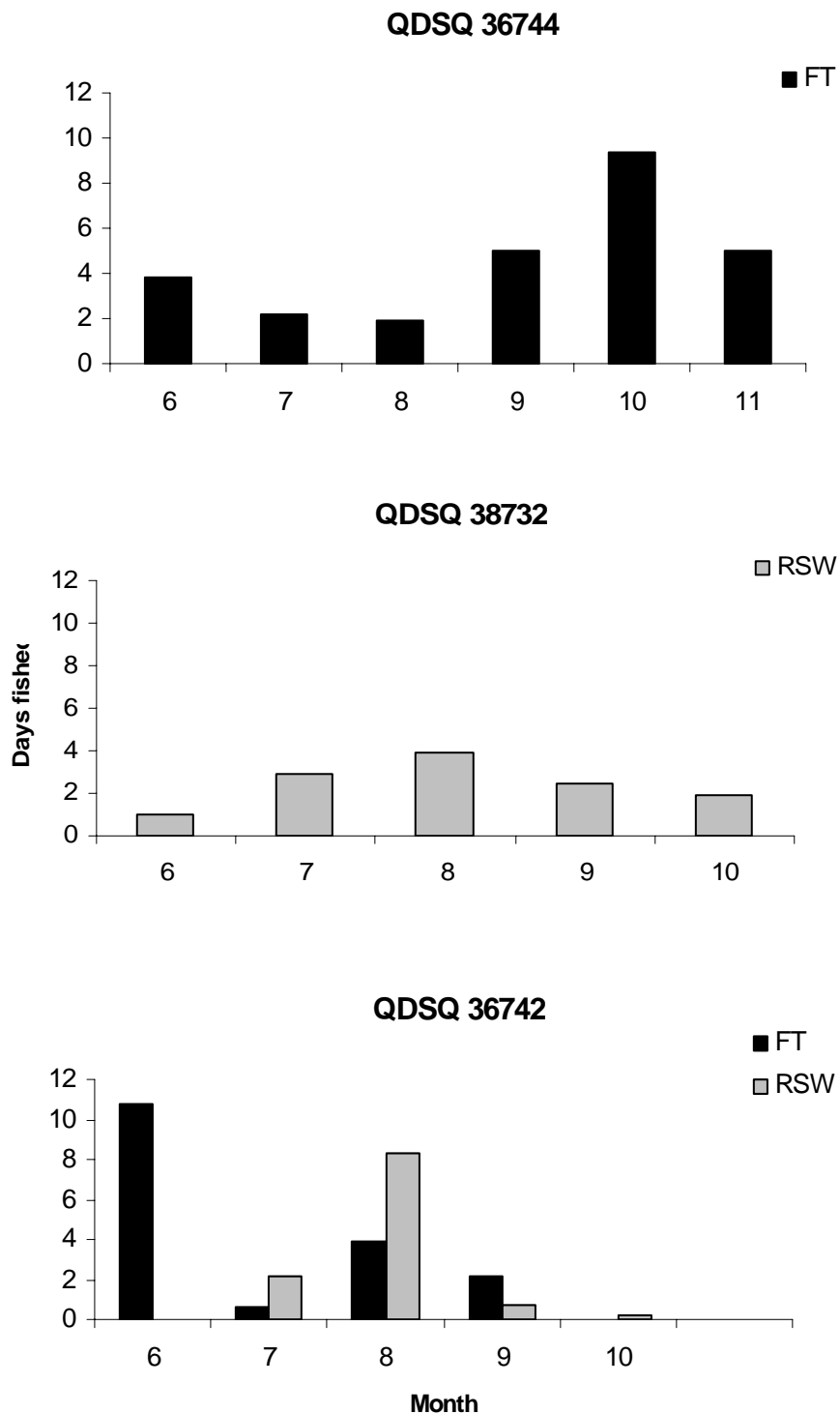


Figure C16. Effort (days fished), by fleet sector and month, in quarter-degree squares that were consistently fished during the 2003 *Illex* fishery. FT represents freezer trawlers and RSW represents refrigerated seawater system trawlers.

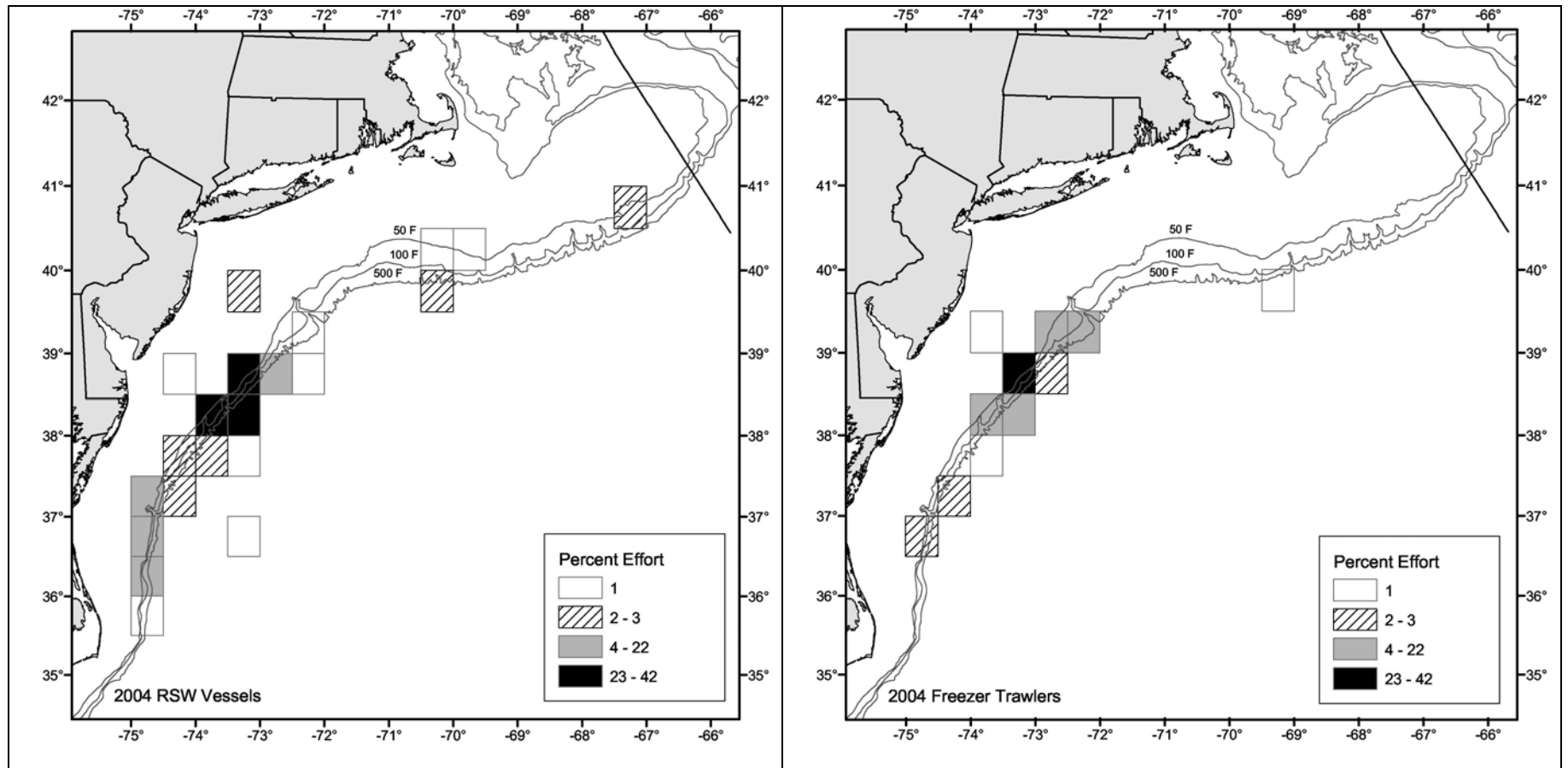


Figure C17. Percentage of nominal annual effort, by quarter-degree square, for refrigerated seawater system (RSW) trawlers and freezer trawlers participating in the *Illex illecebrosus* fishery during 2004.

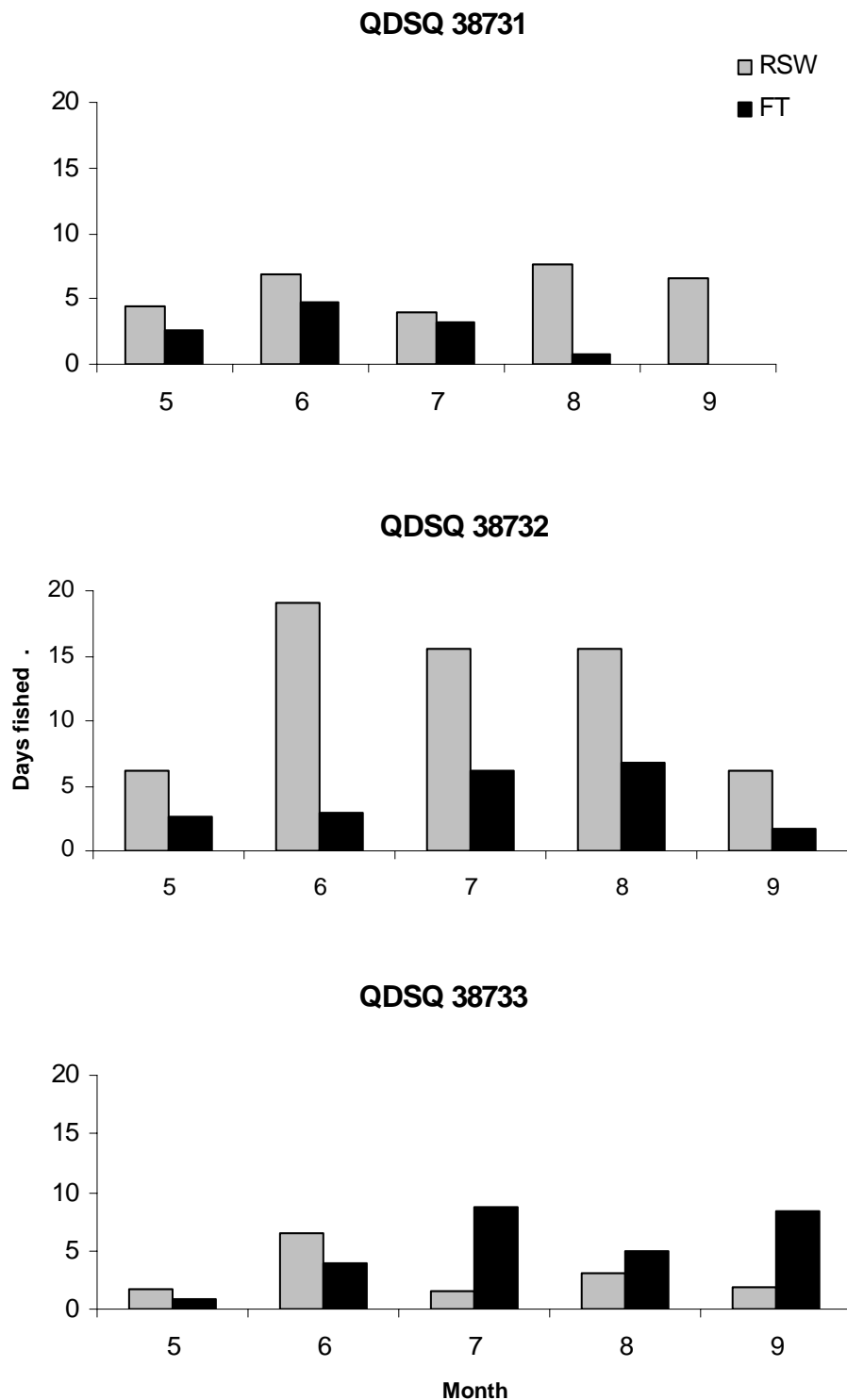


Figure C18. Effort (days fished), by fleet sector and month, in quarter-degree squares that were consistently fished during the 2004 *Illex* fishery. FT represents freezer trawlers and RSW represents refrigerated seawater system trawlers.

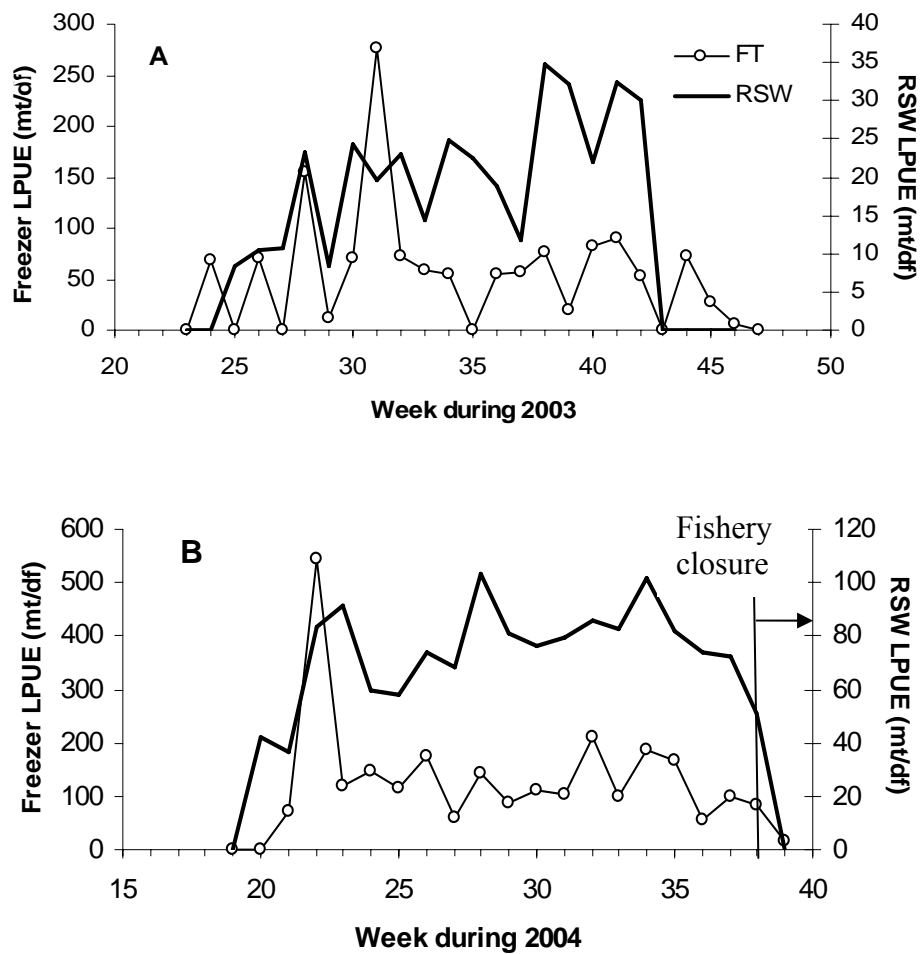


Figure C19. Weekly trends in nominal landings per unit effort (mt/day fished), by fleet sector, in the *Illex illecebrosus* fishery during (A) 2003 and (B) 2004. FT represents freezer trawlers and RSW represents refrigerated seawater system trawlers.

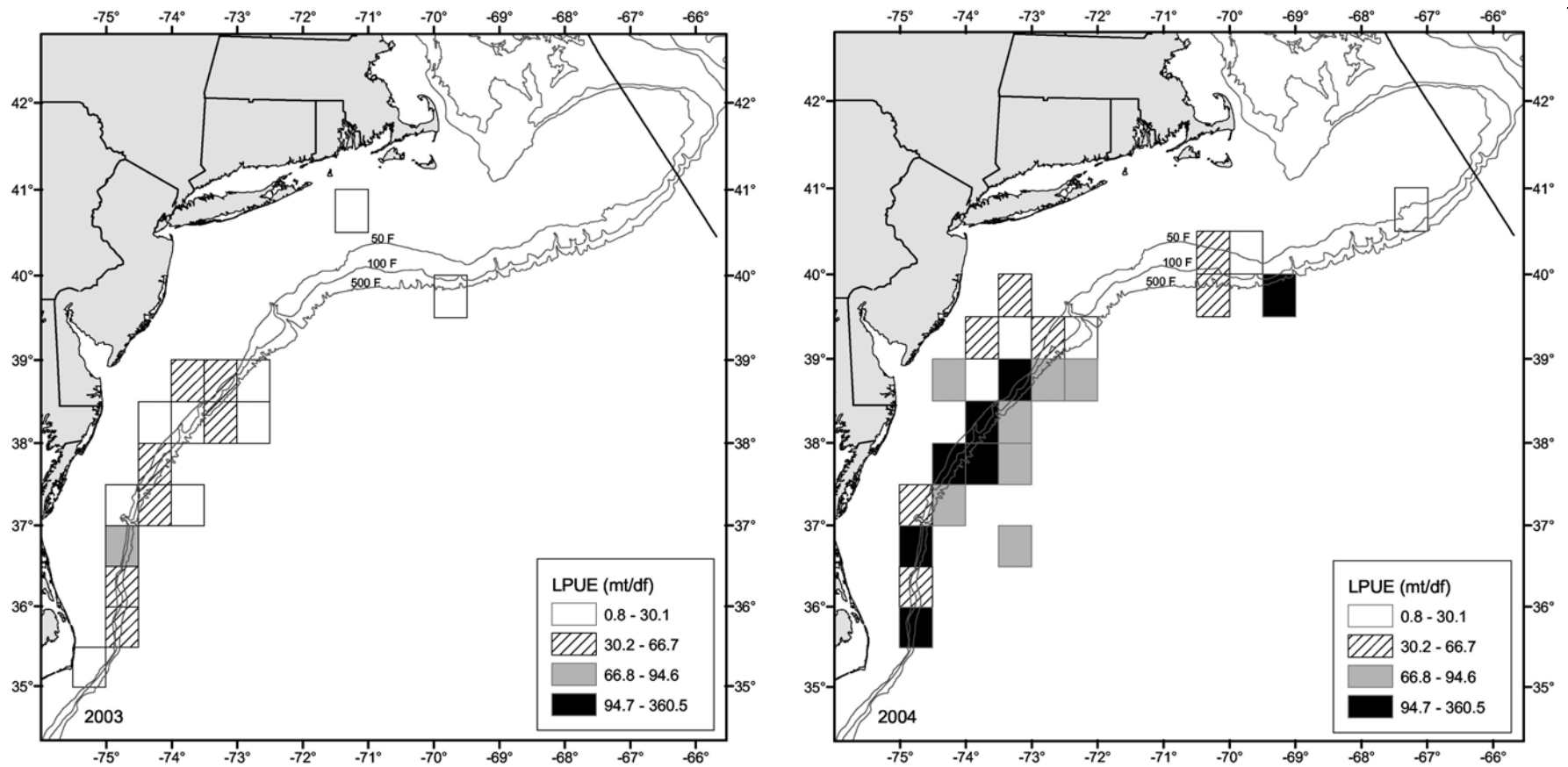


Figure C20. Nominal landings per unit of effort (mt/day fished), by quarter-degree square, for bottom trawlers participating in the *Illex illecebrosus* fishery during 2003 and 2004.

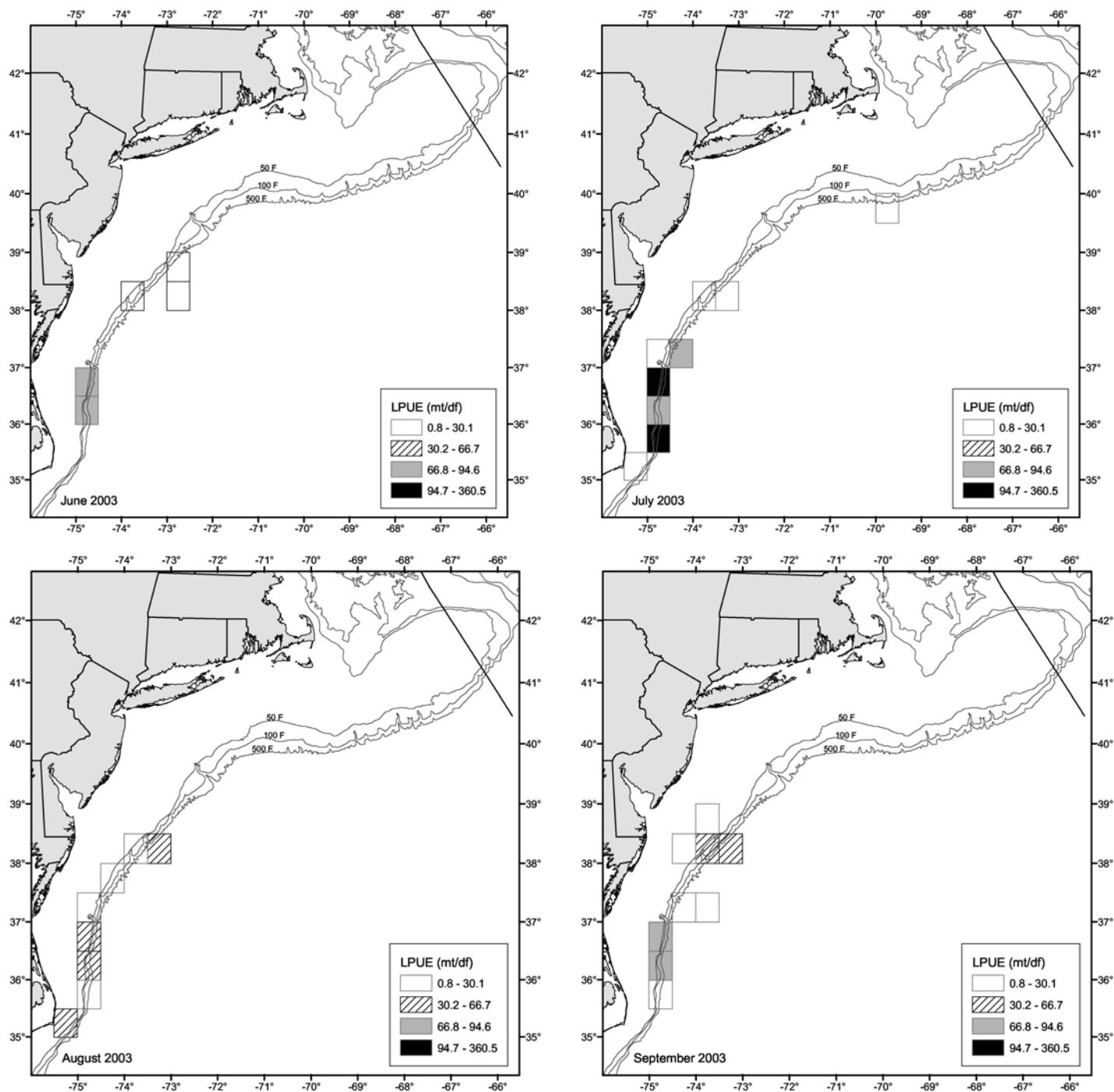


Figure C21. Monthly distribution of nominal landings per unit of effort (mt/days fished), by quarter-degree square, for bottom trawlers participating in the *Illex illecebrosus* fishery during June-October, 2003.

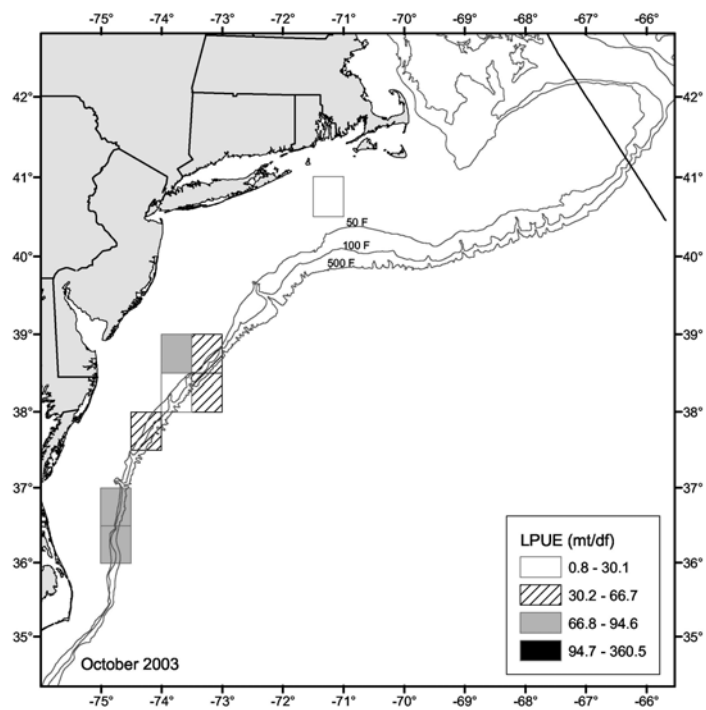


Figure C21. continued

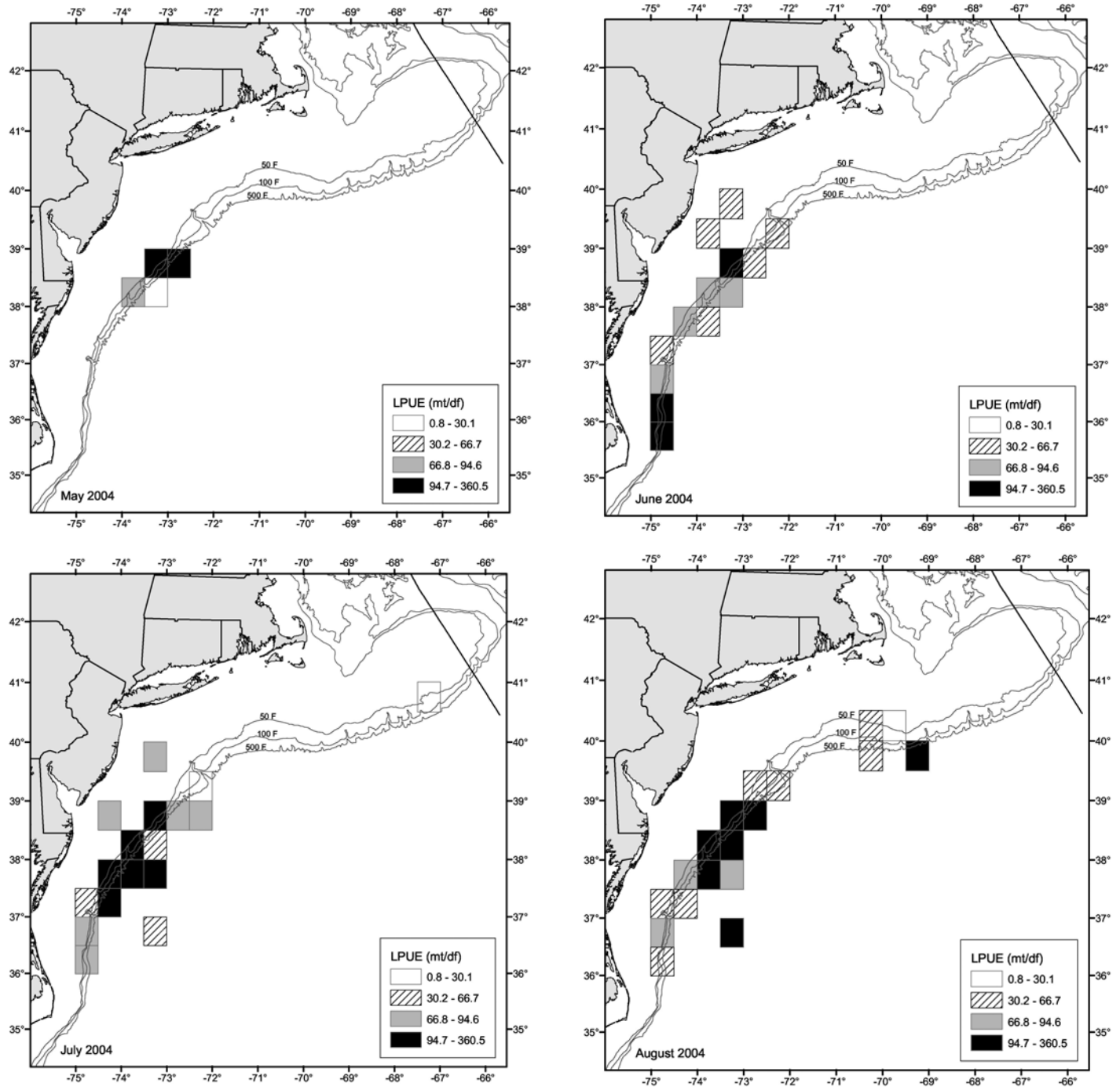


Figure C22. Monthly distribution of nominal landings per unit of effort (mt/days fished), by quarter-degree square, for bottom trawlers participating in the *Illex illecebrosus* fishery during May-September, 2004.

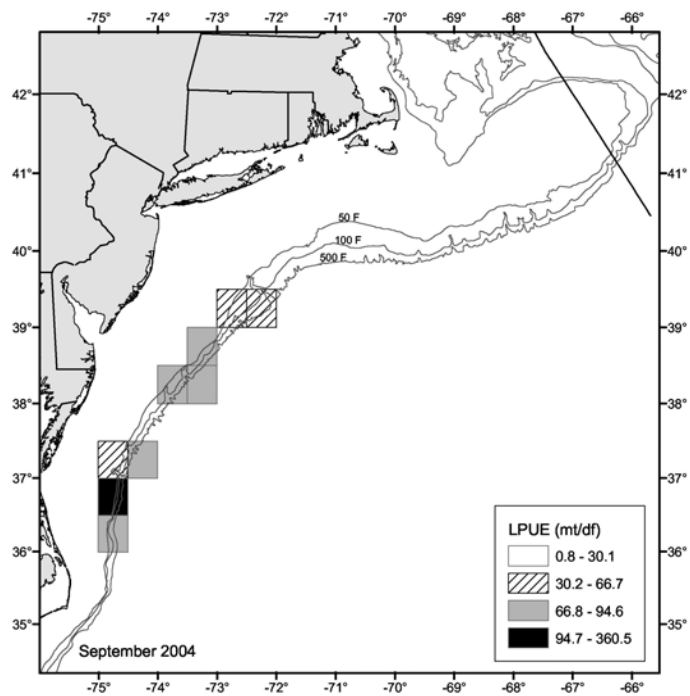


Figure C22. continued

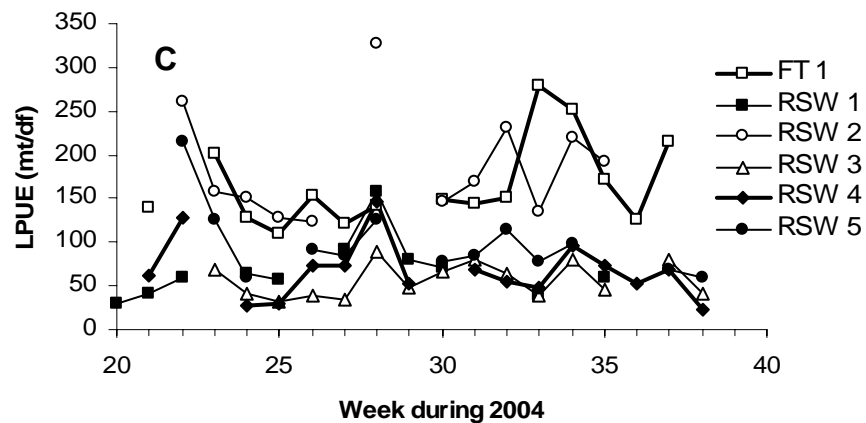
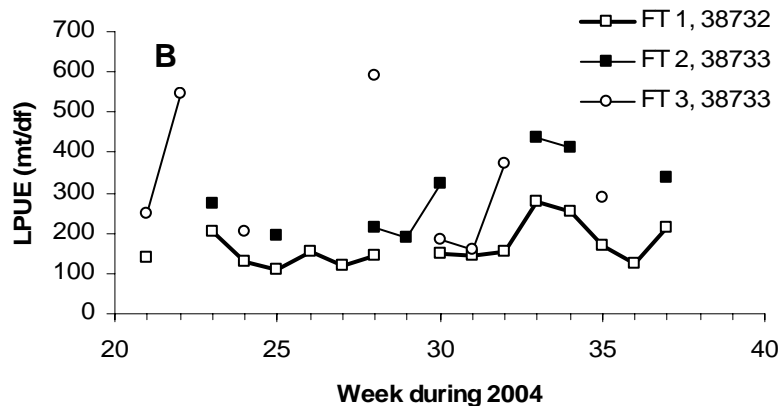
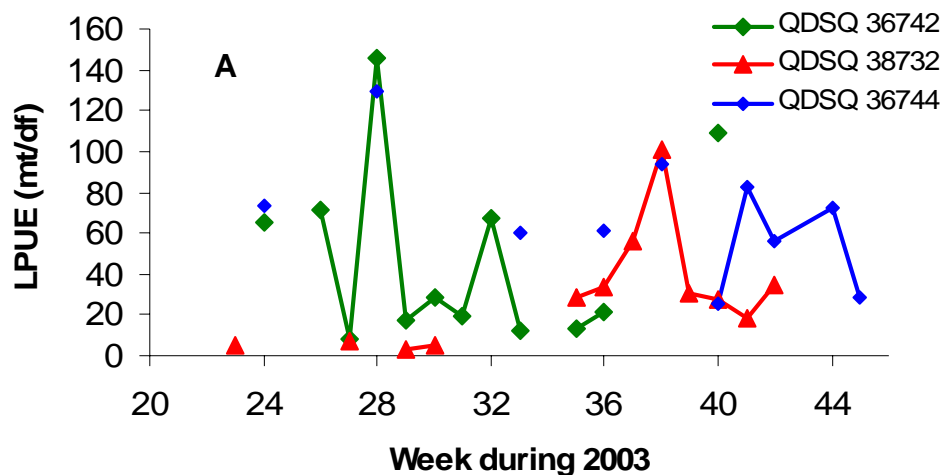


Figure C23. Example of (A) a sequential rise and fall pattern indicated by nominal LPUE for three quarter-degree squares fished by the *Illex* fleet during 2003 and examples of weekly fishing patterns (B) for freezer trawlers quarter-degree squares 38733 and 38732, and (C) for freezer trawlers versus RSW boats in square 38733 during 2004.

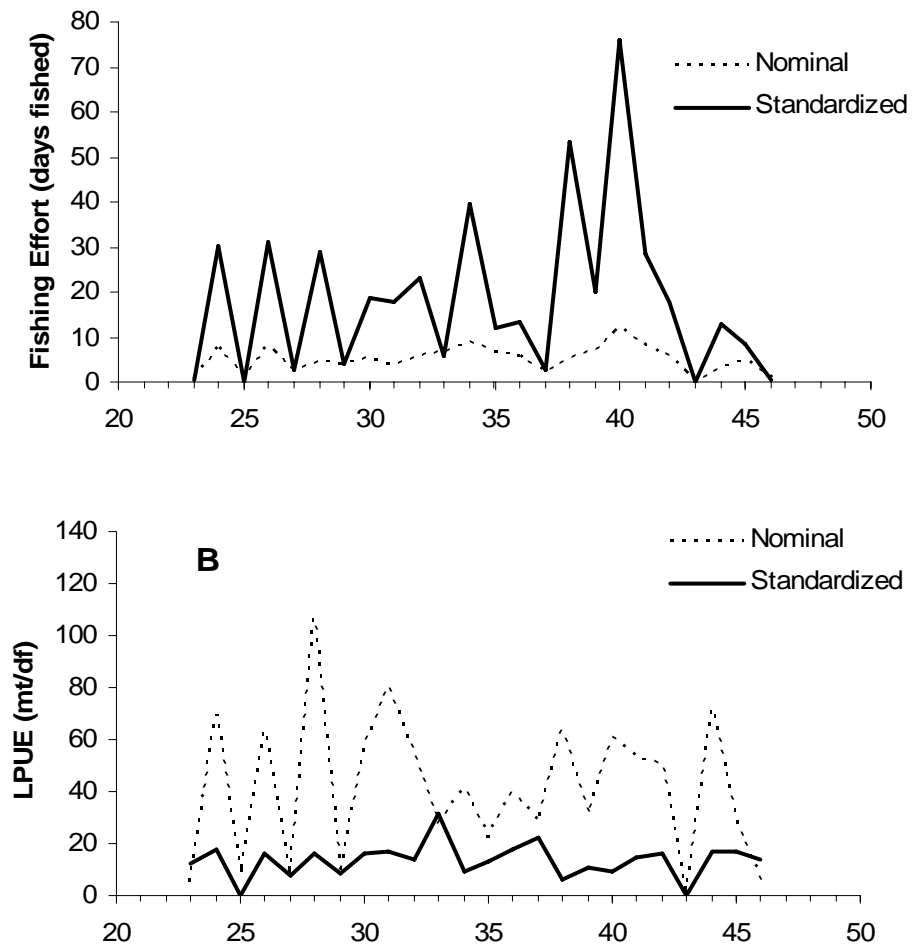


Figure C24. Weekly trends in nominal and standardized (A) fishing effort (df) based on Vessel Trip Report data and (B) LPUE (mt/df) computed from landings and effort data from the VTR Database for 2003.

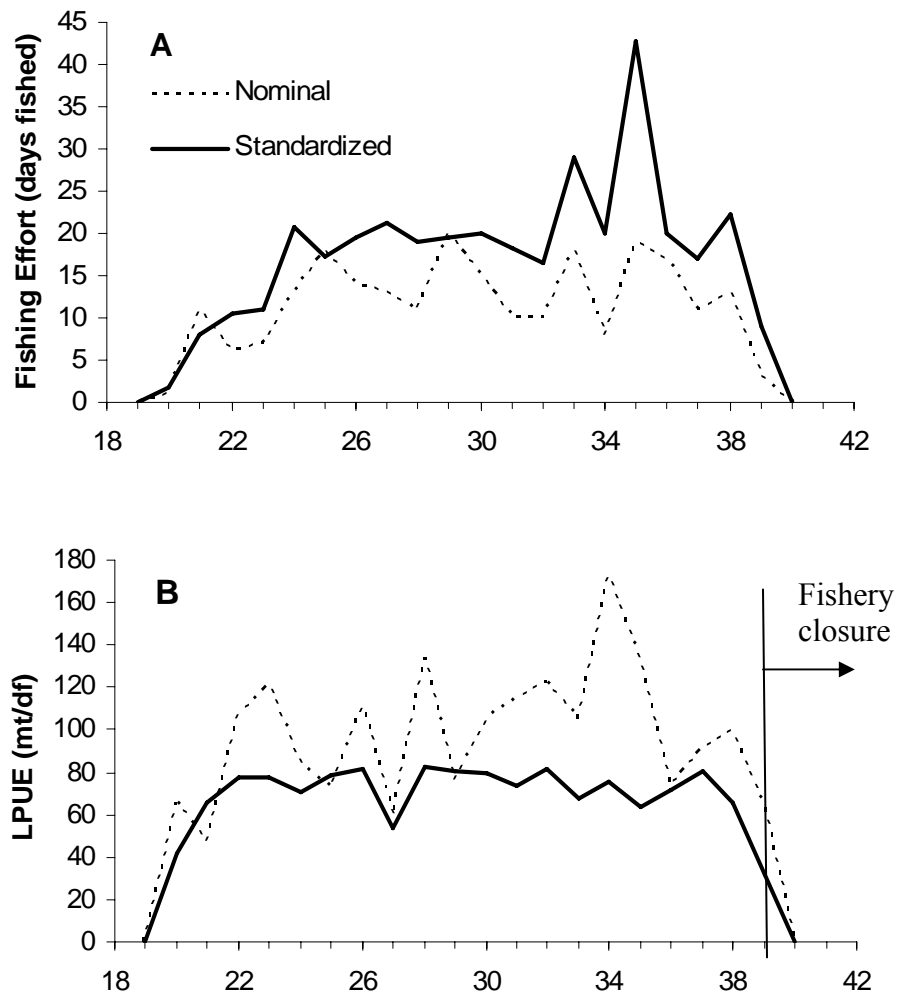


Figure C25. Weekly trends in nominal and standardized (A) fishing effort (df) based on Vessel Trip Report data and (B) LPUE (mt/df) computed from prorated landings from the Weighout Database and effort data from the VTR Database for 2004.

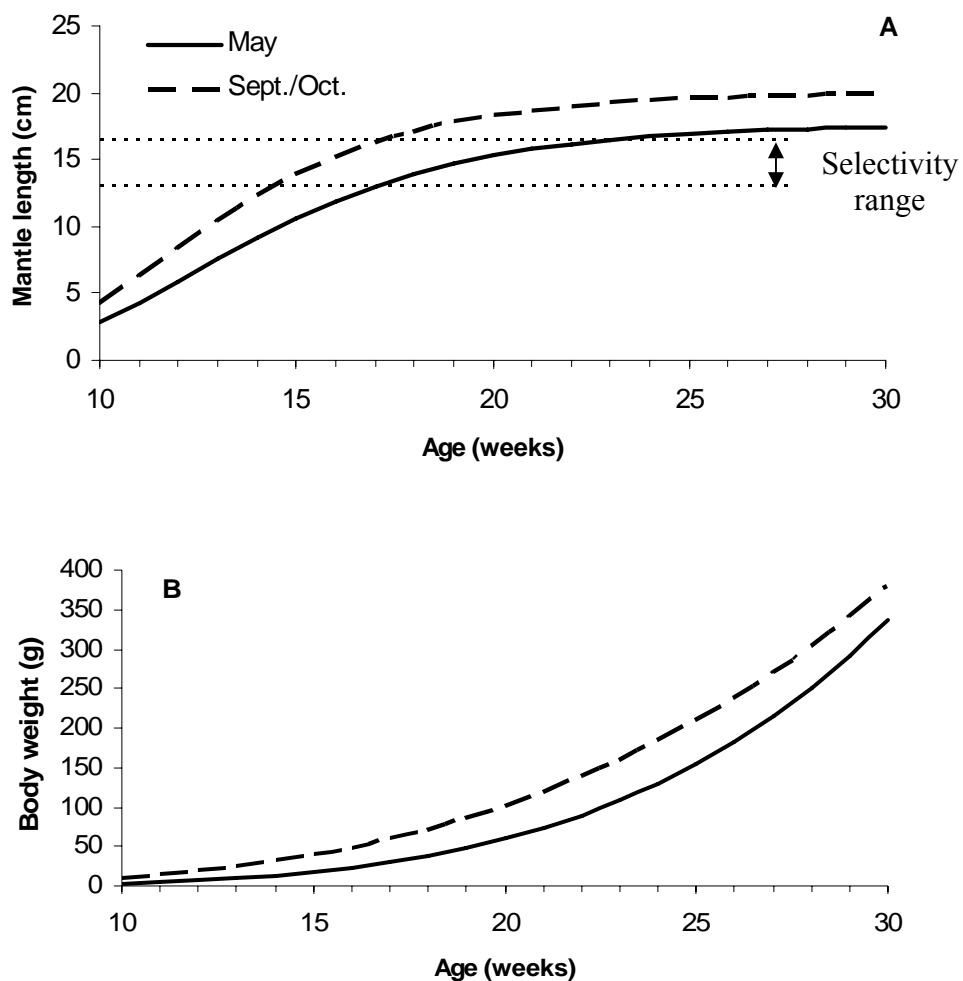


Figure C26 Growth rates of female *Illex illecebrosus* in May versus September/October, during 2000, in terms of (A) length and (B) body weight. The selectivity range shown represents the length range encompassing partial to full selectivity by the fishery and was derived by converting *Illex* lengths from the directed fishery, during 1999-2002, to ages using a weight-at-age relationship from a May 2000 *Illex* survey (Hendrickson 2004).

APPENDIX C1: Comments from external reviewer, Lynne Purchase (Renewable Resources Assessment Group, Imperial College London, England), 10/3/05 Working Group meeting

General Comments

The purpose of this workshop was to review data and methodology available for an assessment the *Illex illecebrosus* stock in advance of the future SARC 42 meeting. This document records my observations as an outside observer on the conduct, conclusions drawn and recommendations for future work made from this working group in order to finalise the assessment and supporting data at the next subcommittee stage. Whilst noting that the data from this fishery does not lend itself to the 'standard' squid assessment methodologies, what emerged from presentation and discussion between scientists and representatives of the industry at the working group meeting was a comprehensive, coherent and rigorous synthesis of both commercial and research data in order to summarise and report on current understanding of stock status within a precautionary approach to the fishery.

Specific comments - data characteristics of fishery

Stock distribution, its range, and environmental factors affecting both were clearly defined and presented. The performance pattern within the fishery is a result of the timing and extent of the feeding migration into shelf waters and subsequent spawning migration off the shelf into deeper waters. (A spawning site for the stock was found during the May 2000 survey on the continental shelf.)

The position of the US EEZ stock (NAFO subareas 5 and 6) as a component of a larger management unit encompassing NAFO subareas 3 to 6 was apparent from landings statistics summarised over the history of the fishery since 1963. It was noted that a closure had occurred in the 2004 fishery since the TAC (24,000mt) was reached and that in order to ensure continued sustainability of the stock, adequate spawner escapement from all fishery areas is required.

Length and weight of samples from landings appear to indicate an increasing trend since 2000 when it was noted that animals were smaller and weighed less than in earlier years. It would be beneficial to obtain corresponding information on maturity from these samples in order to ascertain the presence of more than one cohort in the fishery since it is known that recruitment occurs in most months. This could be facilitated either by the training of observers and/or provision of frozen samples to NEFSC for analysis.

Specific comments - assessment models

Assessment of this stock in the context of estimation of absolute stock biomass or fishing mortality rate has not been possible; this is because the DeLury depletion-'no recruitment' type model has proven inappropriate, given observed trends in LPUE within the data from the fisheries. The autumn bottom trawl surveys do not cover the entire habitat range for the stock and so survey indices are not representative, although they do indicate a relative index of spawner escapement. Accordingly, per-recruit models and supporting analyses have and continue

to be developed in order to provide biological reference points in order to minimise recruitment overfishing and to ensure sufficient escapement. Key to this development are egg- and yield-per-recruit models in which non-spawning and spawning natural mortality is accounted for explicitly.

This represents a new approach compared to the assumption of constant natural mortality for animals of all ages adopted in most other cephalopod assessments in which fishing takes place on a spawning population. Whilst the ‘trigger’ for onset of spawning maturity remains largely unknown, this approach reflects the observation that within semelparous species, such as *Illex*, it is the older individuals that are most likely to become mature, to spawn and then die. Far from being constant, it is much more the case that natural mortality increases over the range of ages at which spawning occurs.

The age-based cohort model developed for estimating spawning mortality (maturation-mortality model) and application of these mortalities within per-recruit models (which are highly sensitive to assumptions about natural mortality) for *Illex illecebrosus* was presented comprehensively with detailed supporting analysis.

Whilst it was noted that this model has also been peer reviewed prior to publication, in the context of testing its overall robustness and general applicability, it is worth underlining the caveat that this model has been developed on the basis of age and maturity data from one survey (May, 2000). Analyses from other squid fisheries indicate that there is often significant intra- and interannual variation in growth and maturation rates. As indicated in the course of the workgroup meeting, the effect of this on the model needs further study and, in this context, it may be worth seeking out data

(*ie.*, biological data in which age has been recorded in addition to the more usual sex, maturity, length and weight) from other, similar cephalopod fisheries. This would extend testing of this model in a cost-effective and timely manner.

The estimates of non- and spawning mortalities have been used within the ‘in-season’ model developed to estimate initial abundance and total fishing mortality from real-time data. Again, it appears that the use of growth and age data from the May survey is a major source of uncertainty in this method. It was noted that current simulation analyses of this ‘in-season’ stock assessment model should be extended to assess its performance and to highlight the need for any additional data.

A better understanding of trends in ‘in-season’ LPUE are important if LPUE is to be used in future monitoring of the fishery as an indicator of abundance of squid within a given fishing area. It was noted that GLM analysis undertaken to standardise effort data within the model required further development and investigation; problematic in this case was the differing behaviour of the two vessel types in terms of trip duration and attributing landings to specific dates; it is possible that repeating this analysis on a time-scale of two- rather than one week periods as main effects may improve the standardisation process in terms of smoothing the data. It is worth noting that effort data may not be smooth over time.

APPENDIX C2: Comments from SARC 42 Working Group meeting 2 (October 24-28, 2005)

The Working Group (WG) reviewed a comparison of the weekly *Illex* landings from the Dealer Weighout database versus the Vessel Trip Report (VTR) database for 1999-2004. During all years except 2004, the weekly landings reported in the VTR database were of similar magnitude. The WG discussed the discrepancy between the weekly landings reported in the two databases for 2004 and noted that one possible reason for the discrepancy is the increase in effort by RSW boats in 2004 in comparison to 2003. Reporting of the kept fraction of the catch by RSW captains is likely to be less accurate, because unlike freezer boats, catches are not boxed and weighed at sea. However, it was unknown whether underreporting in 2004 was greater for RSW vessels than freezer trawlers and the number of vessels from both fleet sectors increased between 2003 and 2004.

The WG noted that fewer vessels were involved in the 2003 fishery and suggested a comparison of VTR landings by vessel during 2003 and 2004 to determine whether underreporting in 2004 was due in part to a change in behavior of captains who reported accurately in 2003 or due to the addition of RSW vessels with poorer reporting accuracy.

The WG noted the possibility that part of the 2004 end-of-season decline in the number of trips after week 34 was due to a temporary shut down at one of the main *Illex* processing plants, Lund's Fisheries, for maintenance.

The WG discussed the trends in the percentage of survey tows in which *Illex* was caught with respect to whether increases in relative abundance were associated with increases in dispersion indices. The WG noted the importance of distinguishing between changes in geographic distribution that may affect the number of positive tows and changes in abundance that would also influence the number of positive tows particularly given that the NEFSC surveys only cover a portion of *Illex* habitat.

The WG noted that R^2 value from the General Linear Models (GLM) were relatively high in comparison to GLM runs for groundfish fleets. It was suggested that a histogram or other plot of the catch rate data would be useful to judge how well the *Illex* fishery data conform to the GLM model assumption of log-normality.

The WG noted that some of the weekly and bi-weekly variability in nominal landings per unit effort (LPUE) was due to the duration of freezer trawler trips which tend to be of one to two weeks in duration with trip departure and return days that consistently occur on similar days of the week (e.g., Monday and Saturday). A suggestion was made to evaluate the use of a running average of LPUE to minimize the week-to-week noise, especially in 2003, when the catch was dominated by freezer trawlers who employ this fishing strategy.

The Working Group was concerned that the underreporting of landings in the 2004 VTR reports might affect the LPUE estimates for 2004 and suggested the use of the 'week' coefficients from the GLM to back-calculate standardized model effort.

Several models were improved and carried forward from the last assessment. These models showed improvement over the last assessment but issues of data availability and model formulation still remain. The WG agreed that continued development of the models presented is important because the approaches being used appear to be valid for this semelparous species.

The WG expressed concern about the representativeness of the maturity ogive given that it was derived from data collected in May and therefore may not describe maturity trends throughout the course of the entire fishing season. The WG recommended collecting in-season age and maturity data to assess how changes in growth, maturity and recruitment influence model output.

The WG noted that the in-season assessment model has a basic assumption that maturity is age-dependent and that selectivity is length-dependent and expressed concern about whether the age- and length-based assumptions were compatible.

The WG noted that selectivity is complicated, particularly during the latter part of the fishing season due to emigration of large females to spawn, recruitment, cannibalism, and possible increases in growth rates. This might result in a dome-shaped selectivity curve at that time. The WG noted that the late-season decline in squid size/weight has a number of competing explanations that may influence the model differentially depending on, for example, the relative importance of off-shelf migration versus spawning mortality.

The WG discussed the possibility that the in-season model may not be formulated correctly for recruitment during the fishing season and suggested that alternative methods of quantifying recruitment be examined. For example, the model could be allowed to estimate recruitment by subtracting M plus F from the initial stock size and assuming that F equals zero.

APPENDIX C3: Maturation-Natural Mortality Model

See Hendrickson and Hart (2006).

APPENDIX C4: Per-recruit Models

See Hendrickson and Hart (2006).

APPENDIX C5: In-season Assessment Model

In-season assessment model formulation and input data

An in-season stock assessment model that was reviewed at SARC 37 was deemed preliminary and subject to further testing. Additional testing of a revised version of the SARC 37 model was conducted during the current assessment using input data for 2003 and 2004 in addition to output data from simulation analyses. The model revision involved a change to the objective function as described below.

The model was designed to estimate weekly stock size and fishing mortality rates of the *Illex* population (in numbers) on the U.S. shelf according to the equation:

$$N_{t+1} = N_t \exp(-Z) + r_t \exp(-M_{NS}),$$

where N_t is the population numbers in week t , Z is total mortality, r_t is recruitment to the exploitable size classes in week t , and M_{NS} is natural mortality due to causes other than spawning (e.g., predation). The predicted catch \hat{C}_t (in numbers) in week t was calculated using the catch equation:

$$\hat{C}_{t+1} = N_t F_t [1 - \exp(-Z)]/Z$$

The weekly fishing mortality rate, F_t , was calculated as:

$$F_t = q S_t E_t$$

where S_t represents the proportion of N_t that is selected by the fishery, E_t is the estimated effort in week t , and q is a constant. Weekly effort (days fished) was computed as the sum of the product of the average tow duration and the number of tows conducted per trip based on data reported by fishermen in the Vessel Trip Report database. Effort was assumed to be proportional to fishing

mortality and was standardized according to the methods described in the above section on fishery LPUE. The aggregated length composition from the landings was used in the calculations presented above.

Individual squid lengths were used for the following purposes:

- (a) to calculate the selectivity function S_t (Fig. C5.1) via the equation:

$$S_t = \frac{\sum_L s_L n_{L,t}}{\sum_L n_{L,t}}$$

where s_L is the estimated selectivity of the length group L , and $n_{L,t}$ is the number of squid of length group L in week t ;

- (b) to estimate recruitment, which was done by applying the May 2000 growth rate for combined sexes (Hendrickson 2004) to the numbers of 13-cm squid observed in the landings (the smallest size retained by the fishery) to estimate one week of growth for these individuals. Thereafter, these lengths were divided by the proportion selected by the fishing gear.

- (c) and to estimate natural mortality, where the number, $n_{a,t}$, at each age group a and week t was back-calculated from the length composition using the May 2000 growth rate for combined sexes (Hendrickson 2004). Total natural mortality, m_a (both spawning and non-spawning mortality), for each age group (in weeks) was estimated from the maturation-natural mortality model. Total natural mortality was computed as:

$$M_t = \frac{\sum_a m_a n_{a,t}}{\sum_a n_{a,t}}$$

The Gompertz growth curve used in the calculation of equations (b) and (c) above was computed from data collected during a pre-fishery *Illex* survey conducted in May 2000. However, since *Illex* grow larger as the season progresses, the asymptotic size of the May growth curve was exceeded. Nearly all of the squid caught during the last few weeks of the season consisted of lengths that exceeded the estimated maximum length observed in May. In order to address the seasonal growth issue, the maximum (asymptotic) mantle length, a , from the May growth curve was adjusted upward each week and estimated as the 95th percentile of the length-frequency distribution of the weekly landings.

The model estimates the initial abundance, N_0 , and total fishing mortality, F_{TOT} . F_{TOT} is the sum of the weekly fishing mortality rates of fully-recruited squid for the entire fishing season and was computed as:

$$F_{TOT} = \sum_t qE_t$$

The SARC 37 version of the model estimated the values of these two quantities by minimizing a chi-square statistic:

$$\chi^2 = \sum_t (C_t - \hat{C}_t)^2 / \hat{C}_t$$

subject to the constraint

$$\sum_t C_t = \sum_t \hat{C}_t$$

where C_t is the observed catch in week t .

The revised version of the model allows for the possibility of fitting one of the maturity ogive parameters, α , together with F_{TOT} and N_0 . Because there may be prior information regarding these parameters (in particular, α), and because there may be insufficient information to freely fit all three parameters simultaneously, penalty terms were added to allow for deviations from the originally estimated values, so that the new objective function is:

$$\sum_t (C_t - \hat{C}_t)^2 / \hat{C}_t + k_1 (N_0 - \hat{N}_0)^2 + k_2 (F_0 - \hat{F}_0)^2 + k_3 (\alpha - \hat{\alpha})^2 + k_4 [\sum_t C_t - \sum_t \hat{C}_t]^2$$

where N_0 , F_0 , and α are the prior estimates of these parameters, with posterior estimates denoted by circumflexes, and the k_i terms are weightings reflective of the confidence in these values.

In-season model results

Model runs using the 2003 data indicated that the results were sensitive to varying the initial guesses of N_0 and F_{TOT} . The results also indicated that a broad range of N_0 and F_{TOT} values were plausible because the χ^2 statistic was relatively flat over large portions of parameter space. Thus, there is considerable model uncertainty regarding the exact values of these parameters. The model fits were poor for both 2003 and 2004 and are not presented herein.

Simulation model formulation and input data

A simulation model was developed to output simulated data sets to test and calibrate the in-season assessment model. The simulation model works similarly to the per-recruit model that takes into account maturity and spawning mortality, but the simulation model also includes a term for recruitment and is a discrete (weekly) model structured by age and maturity status.

The dynamics of non-mature squid [$N_t(a)$] and mature squid [$S_t(a)$] at week t and age a (in weeks) is (excluding the plus age group):

$$N_{t+1}(a+1) = N_t(a) \exp(-M_{ns} - F_t(a) - R(a)) + r_t$$

$$S_{t+1}(a+1) = S_t(a)\exp(-M_{ns}-M_{sp}-F_t(a)) \\ + N_t(a)R(a)[(1-\exp(-M_{ns}-F_n-R(a)))/(M_{ns}+F+R(a))][(1-\exp(-M_{ns} - M_{sp}))/(M_{sp}+M_{ns})]$$

where r_t is recruitment in week t , $F_t(a)$ is fishing mortality in week t on the age a squid, and M_{ns} and M_{sp} are the non-spawning and spawning natural mortality rates, and R is the maturation rate. For the plus group (age a_p),

$$N_{t+1}(a_p) = N_t(a_{p-1}) \exp(-M_{ns}-F_t(a_{p-1})-R(a_{p-1})) + N_t(a_p)\exp(-M_{ns}-F_t(a_p)-R(a_p)) + r_t \\ S_{t+1}(a_p) = S_t(a_p)\exp(-M_{ns}-M_{sp}-F_t(a_p)) + S_t(a_{p-1})\exp(-M_{ns}-M_{sp}-F_t(a_{p-1})) \\ + N_t(a_p)R(a_p)[(1-\exp(-M_{ns}-F_t(a_p)-R(a_p)))/(M_{ns}+F(a_p)+R(a_p))][(1-\exp(-M_{ns} - M_{sp}))/(M_{sp}+M_{ns})] + \\ N_t(a_{p-1})R(a_{p-1})[(1-\exp(-M_{ns}-F_t(a_{p-1})-R(a_{p-1})))/(M_{ns}+F(a_{p-1})+R(a_{p-1}))][(1-\exp(-M_{ns} - M_{sp}))/(M_{sp}+M_{ns})]$$

Non-spawning and spawning natural mortality parameters were taken from the maturity-natural mortality model (Hendrickson and Hart, 2006) and set to $M_{ns} = 0.06$ and $M_{sp} = 0.55$ for all model runs. Fishing mortality varies by age and the same selectivity-at-age ogive used in the per-recruit models was applied in the simulation models. Landings (in numbers) C_t were calculated from the catch equation:

$$C_t(a) = \sum_a \{ N_t(a)F_t(a)[1-\exp(-M_{ns}-F_t(a))]/[M_{ns}+F_t(a)] + \\ S_t(a)F_t(a)[1-\exp(-M_{ns}-M_{sp}-F_t(a))]/[M_{ns}+M_{sp}+F_t(a)] \}$$

Catches in numbers were converted to weights using a weight-at-age relationship, for combined sexes, from the May 2000 *Illex* survey (Hendrickson 2004):

$$W(a) = \varepsilon a^\phi, 1.12 \times 10^{-6}, \phi = 3.6.$$

Simulation model runs were conducted for a fishing season of 19 weeks at various levels of constant fishing mortality, various trends in fishing mortality (increasing, decreasing, and increasing then decreasing), various levels of recruitment, and with observation noise for all variables set to 10%. With the exception of model runs 10 and 11, recruitment was assumed to be constant except for a pulse of recruits which assumed to be twice as large in weeks 7-9 as during other weeks. The outputs from the simulation model were input into the in-season assessment model to evaluate the ability of the in-season model to recover the fishing mortality and N_0 estimates from the simulations.

Simulation model results

In most cases, the in-season model was able to find excellent fits to the data. As often is the case with forward-projecting models, the estimated values of F_{TOT} and N_0 were often estimated with some error, though the product of these two quantities was typically estimated close to the simulated values (Table C5.1). Allowing the in-season model to estimate the maturity parameter with a Bayesian penalty function did not consistently improve the estimates, possibly because the model was already achieving a good fit to the simulated data. Adding noise to the simulated data

only mildly worsened the ability of the in-season model to recover the original parameter estimates.

It can be concluded that if the biological and fishing processes are being modeled correctly, the in-season model can usually estimate total fishing mortality and initial abundance to within 50%, and the product of these two quantities is more accurately estimated than either of them individually.

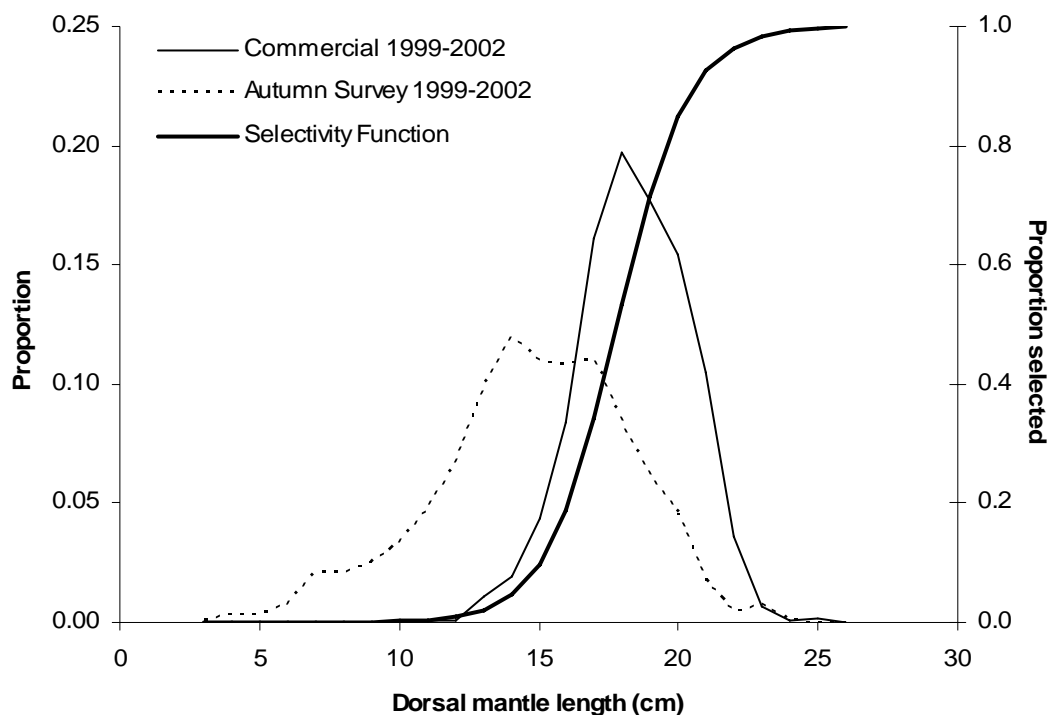


Figure C5.1. Composite length compositions, for 1999-2002, of *Illex illecebrosus* from the NEFSC autumn bottom trawl surveys (strata 1-12 and 61-76) and directed fishery landings.

Length samples from the two sources were subset to include data from similar time periods and geographic areas during each year to derive the selectivity curve shown.

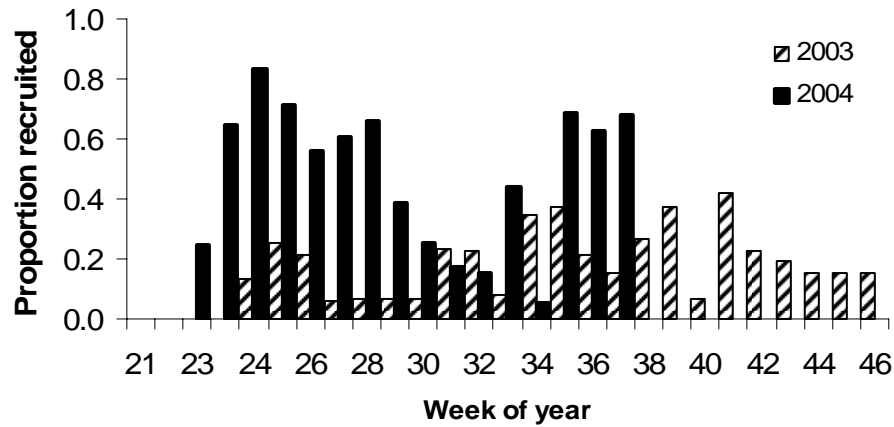


Figure C5.2. Proportion of *Illex illecebrosus* recruitment, by week, during 2003 and 2004.

Table C5.1. Results of simulation model runs under various input scenarios that included maturity ogive parameters of $\alpha = -7.93$ and $\beta = 0.0435$ (Hendrickson, 2004). F_{TOT} is the fishing mortality rate for fully-recruited squid over the entire fishing season.

Model Run	Scenario	Alpha Maturity Parameter	Penalty	Estimated				% Error		
				F_{TOT}	F_{TOT}	N_0	χ^2	F	N_0	$F \cdot N_0$
1	Constant F	Baseline		0.95	2.53	95,428	45	166.3	61.8	1.7
	$N_0 = 250$ mill.	alpha = -7.95	10	0.95	2.58	93,510	45	171.6	62.6	1.6
2	Constant F	Baseline		1.9	2.49	192,393	89	31.1	23.0	0.9
	$N_0 = 250$ mill.	alpha = -8.056	10	1.9	2.88	166,668	88	51.6	33.3	1.1
3	Constant F	Baseline		3.8	4.33	219,018	178	13.9	12.4	0.2
	$N_0 = 250$ mill.	alpha = -8.03	10	3.8	4.62	205,320	178	21.6	17.9	0.1
4	Constant F	Baseline		5.7	5.52	254,412	262	3.2	1.8	1.4
	$N_0 = 250$ mill.	alpha = -8.09	10	5.7	5.97	235,641	261	4.7	5.7	1.3
5	Constant F	Baseline		11.4	7.92	290,473	402	30.5	16.2	19.3
	$N_0 = 250$ mill.	alpha = -8.67	10	11.4	8.67	256,606	399	23.9	2.6	21.9
6	Constant F with noise $N_0 = 250$ mill.	Baseline-Run1		3.8	5.54	166,142	70512	45.8	33.5	3.1
		Baseline-Run2		3.8	4.59	279,201	121739	20.8	11.7	34.9
		Baseline-Run3		3.8	2.71	346,602	63375	28.7	38.6	1.1
		Mean		3.8	4.28	263,982	85209	31.8	28.0	13.0
7	Two-way ramp	Baseline		5.7	5.40	244,486	649	5.3	2.2	7.4
	$N_0 = 250$ mill.	alpha = -6.99	10	5.7	2.22	685,485	357	61.1	174.2	6.8
8	Ramp up	Baseline		5.7	5.17	213,293	502	9.3	14.7	22.6
	$N_0 = 250$ mill.	alpha = -7.25	10	5.7	2.90	451,533	164	49.1	80.6	8.1
9	Ramp down	Baseline		5.7	5.43	285,165	294	4.7	14.1	8.7
	$N_0 = 250$ mill.	alpha = -7.84	10	5.7	5.17	297,526	290	9.3	19.0	7.9
10	Constant F	Baseline		5.7	7.05	190,362	347	23.7	23.9	5.8
	Low recruits	alpha = -8.89	10	5.7	8.99	150,206	304	57.7	39.9	5.2
11	Constant F	Baseline		5.7	4.55	448,721	3093	20.2	79.5	43.3
	High recruits	alpha = -10.55	10	5.7	7.86	252,476	2607	37.9	1.0	39.3

42nd Northeast Regional Stock Assessment Workshop (42nd SAW)

Stock Assessment Report
Part B: Expanded Multispecies
Virtual Population Analysis
(MSVPA-X) Stock Assessment Model

U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Marine Fisheries Service
Northeast Fisheries Science Center
Woods Hole, Massachusetts

May 2006

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Assessment Report (42nd SAW/SARC)

Table of Contents (Volume B)

D: EXPANDED MULTISPECIES VIRTUAL POPULATION ANALYSIS (MSVPA-X) STOCK ASSESSMENT MODEL.....	1
EXECUTIVE SUMMARY	1
TERMS OF REFERENCE	1
PREFACE	5
TABLE OF ACRONYMS	8
CONVERSION TABLE	8
LIST OF VARIABLES.....	9
CHAPTER 1: MODEL STRUCTURE AND FORMULATION	11
1.0 BACKGROUND – THE ICES MSVPA APPROACH.....	11
1.1 FORMULATION OF THE EXPANDED MSVPA (MSVPA-X)	12
1.1.1 Single-species VPA formulation.....	12
1.1.2 Predator Consumption Model	13
1.1.3 Functional Feeding Response	14
1.1.4 Feeding Selectivity Parameters.....	15
1.2 CALCULATION OF PREDATION MORTALITY RATE (M2)	19
1.3 MULTISPECIES FORECAST MODEL.....	21
1.3.1 Ricker Stock-Recruit Relationship	22
1.3.2 Beverton-Holt Relationship	22
1.3.3 Random from Quartiles.....	22
1.3.4 Shepherd Flexible	23
CHAPTER 2: DATA INPUT AND MODEL PARAMETERIZATION	24
2.0 SINGLE-SPECIES ASSESSMENT DATA.....	24
2.1 ATLANTIC MENHADEN.....	24
2.1.1 Summary of Fishery and Assessment.....	24
2.1.2 Fishery Catch-at-Age	25
2.1.3 Fishery-Independent and Dependent Tuning Indices	25
2.1.4 Age and Growth.....	26
2.1.5 Single-Species VPA Formulation	26
2.2 STRIPED BASS	27
2.2.1 Summary of Fishery and Assessment.....	27
2.2.2 Fishery Catch-at-age	27
2.2.3 Fishery-Independent Surveys.....	28
2.2.4 Age and Growth.....	28
2.2.5 Single-Species VPA.....	28
2.3 WEAKFISH.....	29
2.3.1 Summary of Fishery and Assessment.....	29

2.3.2 Fishery Catch-at-age	30
2.3.3 Fishery-Independent Surveys.....	30
2.3.4 Age and Growth.....	30
2.2.5 Single-Species VPA.....	30
2.4 BLUEFISH	31
2.4.1 Summary of Fishery and Assessment.....	31
2.4.2 Biomass Input	32
2.4.3 Size Structure.....	32
2.5‘OTHER PREY’ COAST WIDE BIOMASS ESTIMATES	32
2.5.1 Benthic Invertebrates	32
2.5.2 Macrozooplankton	33
2.5.3 Benthic Crustaceans.....	33
2.5.4 Squid and Butterfish	34
2.5.5 Clupeids	35
2.5.6 Anchovy.....	36
2.6 DIET SELECTIVITY INDICES	38
2.7 SPATIAL OVERLAP INDICES.....	40
2.7.1 Model Spatial Domain	40
2.7.2 Striped Bass	41
2.7.3 Weakfish	41
2.7.4 Bluefish.....	42
2.7.5 Menhaden.....	42
2.7.6 Other Fish Prey	42
2.7.7 Anchovy and Invertebrate Prey	43
2.7.8 Spatial Overlap Indices	43
CHAPTER 3: MODEL PERFORMANCE AND SENSITIVITY ANALYSES	44
3.0 SUMMARY	44
3.1 SINGLE-SPECIES CONFIGURATIONS	44
3.2 MSVPA-X CONFIGURATION.....	45
3.2.1 New MSVPA Configuration.....	45
3.2.2 Enter time frame for MSVPA	45
3.2.3 Enter Other Prey Data.....	46
3.2.4 Enter Prey Preferences.....	46
3.2.5 Enter Spatial Overlap Data	46
3.2.6 Enter Size Preference and Consumption Parameters.....	46
3.2.7 Enter Seasonal Mean Gut Fullness	46
3.2.8 Select SSVPA for each species.....	46
3.3 FORECAST MODULE	47
3.3.1 Configure a Forecast Model.....	47
3.3.2 Enter von Bertalanffy Parameters.....	47
3.3.3 Stock-Recruit Parameters.....	47
3.3.4 Configure Forecast Scenarios	47
3.4 BASE RUN RESULTS.....	47
3.4.1 Population sizes	47
3.4.2 Diet composition.....	48

3.4.3 Consumption and prey availabilities.....	48
3.4.4 Menhaden Predation mortality (M2)	49
CHAPTER 4: MODEL UTILITY FOR MANAGEMENT PURPOSES.....	50
CHAPTER 5: ASMFC RESEARCH RECOMMENDATIONS	53
5.0 SINGLE-SPECIES ASSESSMENTS.....	53
5.1 MULTISPECIES RECOMMENDATIONS FROM ASMFC INTERNAL PEER REVIEW	53
5.1.1 Model Formulation	53
5.1.2 Data.....	53
5.1.3 Recommendations for Base Run & Sensitivity Analyses.....	55
5.1.4 Recommendations for Forecast Projection Module.....	55
REFERENCES	56
TABLES	60
FIGURES.....	96
APPENDIX D1: SENSITIVITY ANALYSES	149
D1 1.0 SENSITIVITY ANALYSIS SUMMARY	149
D1 1.1 RETROSPECTIVE BIAS.....	149
D1 1.2 DROPPING “OTHER PREY” ITEMS.....	149
D1 1.3 CHANGE IN M1	150
D1 1.3.1 Age-0, age-1 and total menhaden abundance	150
D1 1.3.2 Menhaden total biomass and spawning stock biomass.....	150
D1 1.3.3 Average fishing mortality for fully recruited age groups	151
D1 1.3.4 Predation mortality (M2) of ages 0 and 1 menhaden.....	151
D1 1.3.5 Conclusions.....	151
D1 1.4 EVACUATION RATES.....	151
D1 1.4.1 Abundance	152
D1 1.4.2 Spawning Stock Biomass.....	152
D1 1.4.3 Predation Mortality (M2).....	152
D1 1.4.4 Fishing Mortality.....	153
D1 1.4.5 Consumption	153
D1 1.5 PREY TYPE PREFERENCES	153
D1 1.5.1 Introduction and Outline of Sensitivity Runs	153
D1 1.5.2 Results of Sensitivity Runs	154
D1 1.5.3 Discussion	157
D1 1.6 WEIGHT-AT-AGE.....	157
D1 1.6.1 Methods.....	158
D1 1.6.2 Results.....	158
D1 1.7 SPATIAL OVERLAP.....	158
D1 1.7.1 Introduction and Outline of Spatial Overlap Sensitivity.....	158
D1 1.7.2 Annual Menhaden M2 Results.....	159
D1 1.7.3 Annual Menhaden Abundance for Ages 0 and 1 Results	159
D1 1.7.4 Annual Menhaden SSB Results	159
D1 1.7.5 Annual Menhaden Average Recruited (2+) F Results.....	160

D1 1.7.6 Predator Diet Composition Results.....	160
D1 1.7.7 Total Predator Consumption by Prey Type Results.....	160
D1 1.8 PREY SIZE PREFERENCE	161
D1 2.0 FORECAST PROJECTION RESULTS AND ACCURACY	164
D1 2.1 FORECAST MODULE ACCURACY	164
D1 2.2 FORECAST MODEL RESULTS.....	164
APPENDIX D1 REFERENCES.....	166
APPENDIX D1 TABLES.....	167
APPENDIX D1 FIGURES	196
APPENDIX D2: ASMFC SINGLE-SPECIES RESEARCH RECOMMENDATIONS.....	297
ATLANTIC MENHADEN.....	297
STRIPED BASS	302
WEAKFISH.....	304
BLUEFISH	306

D: EXPANDED MULTISPECIES VIRTUAL POPULATION ANALYSIS (MSVPA-X) STOCK ASSESSMENT MODEL

EXECUTIVE SUMMARY

In recent years stakeholder groups, government officials, and scientists have called for an ecosystem approach to fisheries management on both local and federal levels. While managers have traditionally relied on analytical methods to help them make informed choices on a single-species basis, few analytical tools are available to evaluate decisions at the ecosystem level. The Expanded Multispecies Virtual Population Analysis (MSVPA-X) was conceived to support to fisheries management decisions made in a multispecies context.

TERMS OF REFERENCE

1. Evaluate adequacy and appropriateness of model input data, including fishery-dependent data, fishery-independent data, selectivities, etc. as configured. Chapter 2

This configuration of the MSVPA-X utilized the best available single-species assessment and diet data, attempted to fill the data gaps, and tested the model formulation and structure through sensitivity analyses. The results are presented to assess the feasibility of the MSVPA-X model. Utilization for management purposes will require updated single-species assessments, diet matrices, and other relevant information.

Atlantic menhaden: Atlantic menhaden are the only explicitly modeled prey species in this configuration of the MSVPA-X. The XSA is used as the single-species assessment model because it incorporates fishery independent survey data as tuning indices and is consistent with the approach used in the forward-projection single-species assessment model.

Striped bass: XSA is used as the single-species VPA model for striped bass, which is a predator species in this application. The XSA approach is similar to the ADAPT VPA methodology utilized in the single species striped bass stock assessment in that it utilizes tuning indices in the estimation procedures for fishery mortality rates.

Weakfish: The XSA model is used as the single-species VPA approach for weakfish, which is a predator species in this configuration of the MSVPA-X. A series of XSA evaluation runs were developed for the period from 1982-2000 for comparison to the ADAPT VPA and integrated catch-at-age (ICA) analysis used in the 2002 assessment document.

Bluefish: Due to the unavailability of catch-at-age information from a peer reviewed stock assessment during the model reference period (1982 – 2002), bluefish is included in the MSPVA-X application as a “biomass predator”. In this formulation, the predator population dynamics are not modeled. Model input requirements include a time series of total predator biomass, limited information on predator size structure, and feeding selectivity parameters. The biomass dynamics model (ASPIC) previously used to assess the bluefish stock utilized

commercial and recreational landings data. The recreational CPUE and NEFSC inshore fall survey are used as tuning indices for this approach.

Other Prey: To account for available non-menhaden prey, biomass estimates were developed for several “other prey” species groups that comprise important components of the predator species’ diets throughout their life history and range. “Other prey” items included in this configuration include: clupeids (Atlantic herring and threadfin herring); medium forage fish (squids and butterfish); anchovies; sciaenids (spot and croaker); macrozooplankton; benthic invertebrates; and benthic crustaceans. When available, the data and estimates from current stock assessments are utilized; however, for some “other prey” items, biomass estimates are derived using available fishery-independent, fishery-dependent and life-history data. As with the single-species assessments, the MSVPA-X will benefit from improved population estimates for all “other prey” items.

2. Evaluate assumptions for data gap filling when reliable data are not available (diet, biomass of prey species, feeding selectivity). Chapter 2

An extensive review of available diet data for striped bass, weakfish, and bluefish was conducted. There is a general lack of coast wide diet data for all ages of the predator species modeled. The most spatially and temporally comprehensive data set for all three species is the Northeast Fisheries Science Center Food Habits database. However, this survey is limited to the coastal (i.e., non-estuarine) waters, is only available during spring and fall, and generally does not have large sample sizes for older fish. For each species, there are additional regional studies that provide diet information for estuarine waters and other times of the year. The MSVPA-X utilizes a thorough compilation of the available diet data.

Predation mortalities in the standard International Council for the Exploration of the Seas (ICES) MSVPA approach are calculated based upon a simplified feeding model, based on a constant ration for a predator of a given age-class and year. This constant ration does not reflect effects of food availability on feeding rates or temperature effects on predator metabolism. Food consumption rates in fish can vary strongly, particularly between seasons as a function of food availability, changing temperatures, and metabolic demands. To account for these processes, a more detailed consumption model is implemented in the MSVPA-X using the Elliot and Persson (1978) evacuation rate approach, including a modified functional relationship between food availability and predator consumption rates.

The standard MSVPA formulation assumes that predator feeding rates are independent of prey availability, resulting in a Holling type II predator-prey feeding response (Magnusson, 1995). Type II feeding responses result in depensatory dynamics in predation mortality rates, which creates a “predation pit” at low prey biomass that can result in unrealistic model dynamics such as prey extinction due to predation. In contrast, the MSVPA-X employs type III functional responses that are compensatory in nature in that the feeding rate on a particular prey item will decline at low prey abundances, and hence predation mortality pressure is released.

The feeding model also includes a “suitability index”, which is comprised of seasonal spatial overlap of predators and prey, prey type preference and prey size preference. The MSVPA-X

model employs a flexible unimodal function to describe the relationship between prey length and the proportion of the prey in the diet. The size selection index for a prey of a particular size thus corresponds to the predicted proportion of prey of that size in the predator's diet.

The selectivity model used in the MSVPA-X relies upon a rank index for prey type preference. These indices are derived from summaries of available diet composition data when they are available. For the predators considered here, there are multiple diet studies published in the literature; however, these are generally smaller scale studies focusing on particular places, seasons, and time periods.

While the MSVPA-X model is not fully spatially explicit, it is necessary to define a spatial domain and strata at regional scales to evaluate seasonal spatial overlap between predators and prey. The spatial resolution of these strata is primarily limited by available data on the spatial distribution of the species included in the model. The spatial distribution of each taxon is evaluated on a seasonal basis using landings, survey, or regional density data as appropriate. These relative spatial distributions are then used to calculate the seasonal spatial overlap (using Schoener's index) between each predator age class and each prey species.

3. Review model formulation (overall setup, data handling, VPA calculations, assessment options, sensitivity analyses, recruitment model options, and forecast projection options) of model as configured. Chapters 1, 3 and Appendix D1.

The Multispecies Virtual Population Analysis (MSVPA) approach was developed within International Council for the Exploration of the Seas (ICES) as a multispecies extension of cohort analysis or virtual population analysis (VPA). The approach can be viewed essentially as a series of single-species virtual population analysis models that are linked by a simple feeding model to calculate natural mortality rates. The system of linked single-species models is run iteratively until the predation mortality (M2) rates converge. Predation mortality is the portion of natural mortality of a species that is the result of predation by another species. The basic model is performed in two primary iteration loops. First, all single-species VPAs are run to calculate population size at all ages for predators and prey, then predation mortality rates are calculated for all age classes of each species based upon the simple feeding model. The single-species VPAs are run again using the calculated M2 rates, and this iteration is repeated until convergence (reviewed in Magnusson, 1995).

The MSVPA-X approach described here builds upon the framework of the standard MSVPA by incorporating a variety of single-species VPA approaches (including a "tuned" VPA), modification of the consumption model, introducing a weak Type III functional feeding response, formalizing the derivation of selectivity parameters from diet data, altering the size-selectivity model, and including predators without age-structured assessment data. These additions allow for a clearer definition of the input parameters used to model predator diets and consumption rates, and improve the MSVPA equations to reflect processes controlling feeding and predation rates.

Total biomass and spawning stock of striped bass increases over the time series. Weakfish experience fluctuations in total biomass, but a general increasing trend in spawning stock

biomass (SSB) is noted. Bluefish population biomass exhibits high abundance early in the time series (1982 – 1988), declines throughout much of the 1990s, followed by an increase in stock size in the last 3 – 4 years.

The only explicitly modeled prey species in this iteration is menhaden. Total abundance and abundance at maturity (age-2+) decline, although overall SSB has remained stable yet somewhat variable. This is in part due to an increase in weight-at-age for menhaden (ASMFC, 2004a).

4. Develop research recommendations for data collection, model formulation, and model results presentation. Chapter 5

Recommendations for data collection improvements:

- Add a bluefish age-structure/catch-at-age matrix.
- Adult index for menhaden (e.g., an aerial line transect survey) and other species.
- Obtain population weight-at-age estimates.
- Conduct a coast wide diet and abundance study (i.e., an Atlantic coast “year of the stomach”).
- Collect more diet data for all four MSVPA-X species along the entire Atlantic coast.
- Conduct stomach selectivity research for predator species to improve prey ranking matrix.
- Encourage existing fishery-independent surveys to take regular gut contents.
- Evaluate if striped bass disease (mycobacteria) is correlated with natural mortality (M1) and food availability or if disease is disrupting striped bass feeding and causing starvation.
- Estimate carrying capacity for the system to evaluate what model estimates/suggests for carrying capacity.
- Improve estimates of biomass for prey species on coast wide basis.
- Conduct a parallel comparison with ICES MSVPA model on a system that has the necessary data collected (Georges Bank or the North Sea) to identify the differences in results.
- Explore the ability to add other predators to model (birds, mammals, other fish, other systems)
- Explore the utility of implementing the Williamson spatial overlap index in the model
- Investigate type II and type III feeding responses of the MSPVPA-X species in field studies

Recommendations for the improvement of model formulation:

- Add uncertainty to model forecast and incorporate elements of Monte Carlo simulations on recruitment curves.
- Alter biomass predator bin sizes for more flexible way to vary for projection model, if necessary after conducting sensitivity analyses or until an age-structured stock assessment is developed for bluefish.
- Add ICA and production model options to retrospective.
- Develop a similar application to the “amoeba” program that allows the user to easily vary changes to model parameters.

Recommendation for the forecast component of the MSVPA-X:

- Determine the affect sensitivity of the model to the removal of all fishing pressure from system
- Insert recovery benchmarks
- Explore options for adaptive management framework with stock-recruitment options

5. Evaluate whether or not the model and associated data are of sufficient quality to develop recommendations to management. Chapter 4

The model has the potential to improve assessments in single-species assessments by suggesting the predation mortality rate at age (or by year, as appropriate) for explicitly modeled prey species. This has already been accomplished for menhaden in the 2003 assessment (ASMFC, 2004a). An earlier iteration of MSVPA-X produced estimates of menhaden natural mortality at age; however, menhaden population size was estimated using a separate single-species assessment model and overall natural mortality was specified within that single-species assessment.

Additionally, decision makers can be shown potential impacts of fishing and predation mortality by age class for explicitly modeled prey. Such an analysis may suggest optimum harvest strategies for both predators and prey when fisheries for both exist and are managed under the same body. Further analyses may allow for the management of prey using total mortality, rather than fishing mortality. The model may also provide insight on multiple species target biomass based on trade offs among predators and prey. The model may provide guidance for rebuilding predator stocks and the interactions between a specific predator biomass targets and the availability of prey species for other stocks of concern should that target be realized.

Based on thorough review and testing of the MSVPA –X model, the committee suggests that this formulation is capable of answering management questions about predator-prey interactions among explicitly modeled species. With clear understanding the MSVPA-X’s abilities and limitations described fully within the following assessment report, the MSVPA-X approach has the potential to provide much accessory information for fisheries managers.

PREFACE

The MSVPA-X is a new model developed to aid the ASMFC in better quantifying predator and prey interactions and accounting for these effects on both predator and prey populations. In developing the model, the ASMFC conducted an Internal Review of the MSVPA-X to evaluate model formulation, input data, gap filling procedures, and develop recommendations on incorporating the model and its results in Commission stock assessments for individual species. The Internal Review Panel was formed primarily of scientists involved with ASMFC multispecies projects, but also included an expert on the “standard” ICES MSVPA and two stakeholders involved with the ASMFC.

To provide SARC reviewers a framework to evaluate the model using the Terms of Reference listed below, recommendations of the ASMFC Internal Review Panel are included to preface the Terms of Reference. Although the model will be able to estimate multispecies benchmarks and

explore trophic relationships between species, the MSVPA-X is not designed to address all ecosystem level questions or local depletion issues. The ASMFC Panel was comfortable using the model for the following purposes:

- Improve single-species models for single-species population adjustments (i.e., age and year specific inclusion of M)
- Insight on multiple species benchmarks based on species trade offs
- Investigate predation mortality versus catch for important prey species by age class
- Determine the trade offs among harvesting strategies when fisheries exist for both predator and prey
- Develop short-term projections for explicitly modeled species
- Provide guidance for rebuilding predator stocks
- Evaluate change in predator management and its effects on prey and competing predators
- Explore potential feedbacks between lack of prey, abundance of alternative prey, fishing mortality on the predator populations
- Longer projections can be performed as exploratory tool to investigate linkages among species but should not be used as a management tool
- Examine the role of predator consumption in reduced prey recruitment to the fishery

However, the Panel noted this model should not address the following issues:

- Setting reference points or harvest limits for single-species from MSVPA-X
- Estimations of absolute abundance for explicitly modeled species
- Examining local abundance or depletion
- Long-term projections are subject to the limitations of recruitment variability for the prey population and predator populations

**Atlantic States Marine Fisheries Commission MSVPA-X Multispecies Assessment
Subcommittee/Stock Assessment Committee**

The MSVPA-X Multispecies Assessment Subcommittee presented its work to the Stock Assessment Committee on September 28, 2005:

MSVPA-X Multispecies Assessment Subcommittee Members

Matt Cieri – Subcommittee Chair, Maine Department of Marine Resources
Lance Garrison – Garrison Environmental Analysis and Research
Robert Latour – Virginia Institute of Marine Science
Behzad Mahmoudi – Florida Fish and Wildlife Conservation Commission
Brandon Muffley – New Jersey Department of Environmental Protection
Alexei Sharov – Maryland Department of Natural Resources
Doug Vaughan – National Marine Fisheries Service, Center for Coastal Fisheries and Habitat Research

ASMFC Stock Assessment Committee members present:

John Carmichael – Committee Chair, South Atlantic Fisheries Management Council
Matt Cieri – Subcommittee Chair, Maine Department of Marine Resources
Doug Grout – New Hampshire Department of Fish and Game
Kim McKown – New York Department of Environmental Conservation
Brandon Muffley – New Jersey Department of Environmental Protection
Mike Murphy – Florida Fish and Wildlife Conservation Commission
Des Kahn – Delaware Department of Natural Resources
Alexei Sharov – Maryland Department of Natural Resources
Doug Vaughan - National Marine Fisheries Service, Center for Coastal Fisheries and Habitat Research

Dr. Lance Garrison is acknowledged for his continued work with the MSVPA-X Assessment Subcommittee to fine tune the MSVPA-X model formulation, which he developed with Dr. Jason Link (National Marine Fisheries Service).

Appreciation is also extended to the ASMFC striped bass, Atlantic menhaden, weakfish, and bluefish Technical Committees that reviewed the input data that has been utilized in the model and the model formulation.

Special appreciation is given to the ASMFC staff dedicated to the coordinating and assisting the efforts of the ASMFC Multispecies Assessment Subcommittee in the preparation of this document to send to peer review – Patrick Kilduff, Joe Grist and Peter Mooreside. The ASMFC also appreciates the efforts of former staff Dr. Lisa Kline, Geoff White and Jeff Brust on multispecies projects.

TABLE OF ACRONYMS

ADAPT	A VPA that incorporates one or more abundance indices
ASAP	Age Structured Assessment model
ASMFC	Atlantic States Marine Fisheries Commission
ASPIC	A Surplus Production Model Including Covariates
CFDB	Commercial fishery database
CPUE	Catch per unit effort
GIS	Geographic Information Systems
ICA	Integrated Catch-at-Age
ICES	International Council for the Exploration of the Seas
MD DNR	Maryland Department of Natural Resources
MRFSS	Marine Recreational Fisheries Statistics Survey
MSVPA	Multispecies Virtual Population Analysis
MSVPA-X	Expanded Multispecies Virtual Population Analysis
NEFSC	Northeast Fisheries Science Center
NJ DEP	New Jersey Department of Environmental Protection
NJ OTS	New Jersey Ocean Trawl Survey
SEAMAP	Southeast Area Monitoring and Assessment Program
SEFSC	Southeast Fisheries Science Center
SSB	Spawning stock biomass
SSVPA	Single species virtual population analysis
VIMS	Virginia Institute of Marine Science
VPA	Virtual population analysis
XSA	Extended Survivors Analysis
YOY	Young of year

CONVERSION TABLE

Imperial	Metric
1 million pounds	454 metric tons (mt)
1 pound (lb.)	0.454 kilograms (kg)
1 pound (lb.)	454 grams (g)
1 ounce (oz.)	28.35 grams (g)
1 inch (in.)	2.54 centimeters (cm)
1 inch (in.)	25.4 millimeters (mm)
1 foot (ft.)	30.48 centimeters (m)
1 yard (yd.)	.914 meters (m)
1 mile	1.609 kilometers (km)
1 yard ² (yd ²)	0.836 meters ² (m ²)
1 mile ²	2.59 kilometers ² (km ²)
1 yards ³ (yd ³)	meter ³ (m ³)

LIST OF VARIABLES

Definitions of variables described in Chapter I of MSVPA-X Assessment Report.

$R_{i,a}$ - total food consumption rate in biomass for a predator i and age class a

$v_{i,a}$ is a constant ration (biomass prey / biomass body weight)

$w_{i,a}$ is body weight of predator i of age a .

C_{ia}^{ys} - total consumption in year, y , for a predator during a given season, s for predator i , age class a .

SC_s is the mean stomach contents weight relative to predator i age a body weight in a season s ,

D_s is the number of days in the season s

w_{ys} is the average weight-at-age for the predator i age a

N_{ys} is the abundance of the predator i age a during season s in year y .

E_s^{ia} is the evacuation rate for a predator i and age class a in season s - the rate at which food leaves the stomach

$\overline{SC_s^{ia}}$ - an average stomach contents across years for predator i , age class a , in season s

S_{jb}^{ia} - suitability index" for a given prey species, j , and age class, b , for predator species, i , and age class, a is calculated as a product of spatial overlap index, general vulnerability and size selection.

O_{ij} - spatial overlap index, defines similarity of spatial distribution of predator i and prey j based upon the relative abundance of predators and prey in defined areas within the model spatial domain. The index ranges between zero and 1.

A_i - type selection, reflects preference for a particular species relative to all others. Type selection is entered as a proportionalized rank index, equivalent to the expected diet composition for the predator given equal prey abundances and equal prey sizes.

$S(\alpha, \beta)$ - Size selection reflects primarily capture and ingestion probabilities and is a function of relative prey to predator length.

SB_{jb}^{ia} - Suitable biomass, total food available for predator i and age class a

\overline{N}_{jb} - the average number of prey available during the time interval, where α and β are the beginning and end of the time period being considered expressed as a proportion of a year.

P_{jb}^{ia} - The biomass of a particular prey consumed by a predator is the product of total consumption by the predator and the proportion of total suitable biomass represented by that prey type

$M2_{jb}^{ia}$ - the predation mortality rate due to the predator is the ratio of these removals to the average abundance of the prey during the time interval

$M2_{jb}$ - total predation mortality rate for a given prey species and age class is finally the sum across all predators.

CHAPTER 1: MODEL STRUCTURE AND FORMULATION

1.0 BACKGROUND – THE ICES MSVPA APPROACH

The Multispecies Virtual Population Analysis (MSVPA) approach was developed within International Council for the Exploration of the Seas (ICES) as a multispecies extension of cohort analysis or virtual population analysis (VPA). The basic approach was initially described by Pope (1979) and Helgason and Gislason (1979) and later modified and described in Gislason and Helgason (1985). The approach can be viewed essentially as a series of single-species virtual population analysis (SSVPA) models that are linked by a simple feeding model to calculate natural mortality rates. The system of linked single-species models is run iteratively until the predation mortality (M_2) rates converge. The basic model is therefore performed in two primary iteration loops. First, all single-species VPAs are run to calculate population size at all ages for predators and prey, then predation mortality rates are calculated for all age classes of each species based upon the simple feeding model. The single-species VPAs are run again using the calculated M_2 rates, and this iteration is repeated until convergence (reviewed in Magnusson, 1995). The single-species VPAs for the ICES model employ the basic catch equation and VPA approach as described in Gulland (1983) using input values for terminal fishery mortality rates (F) that are generally derived from single-species assessments.

Predator diets, and therefore prey consumption and predation mortality, are driven by feeding selectivity parameters that are assumed constant for a given predator-prey combination. Actual values of selectivity indices may be derived from a simplified feeding model. In the original formulation of the model, these indices were not well defined and the choice of selectivity parameters was arbitrary. The MSVPA approach is therefore implemented by including diet information and an additional iteration loop to solve for appropriate values of the selectivity indices. Diet data must be available for all predators and age classes in a particular year of the time series. To solve for the selectivities in the year where diet data are available, it is necessary to know the abundance (and biomass) of all prey in that year. A third iteration loop is therefore imposed where the MSVPA calculations are performed with arbitrary starting values for selectivity parameters, then the selectivities are solved for based upon diet information, and the iteration loops are repeated with the derived selectivity values until convergence. It is assumed that selectivity values are constant through time and independent of prey abundance.

The MSVPA formulation gives rise to a type-II functional feeding (Holling, 1965) response between prey abundance and predation rates. This is consistent with the interpretation that feeding selectivities are independent of prey abundance. In the case of active “switching”, where more abundant prey items are preferentially consumed and therefore selection is a function of prey abundance, a sigmoid type-III functional response would occur. While it may be desirable to explore a type-III feeding response, the solutions of the MSVPA equations become non-unique under this formulation at even moderate predation mortality rates (Hilden, 1988).

The standard MSVPA approach has been applied extensively by the ICES working group in the North Sea ecosystem. The main conclusions, as summarized in Pope (1991), are that natural mortality rates are high and variable from year to year and that predation mortality may significantly impact recruitment. In addition, changes in mesh size to increase the abundance of

older, larger fish, may result in higher predation rates and lower fishery yields. The MSVPA approach has also recently been applied to the Georges Bank fish community (Tsou and Collie, 2001) with a slightly modified expression for size selectivity and to the groundfish community of the eastern Bering Sea (Livingston and Juado-Molina, 2000).

1.1 FORMULATION OF THE EXPANDED MSVPA (MSVPA-X)

The expanded MSVPA (MSVPA-X) approach described here builds upon the framework of the standard MSVPA by incorporating a variety of SSVPA approaches including a “tuned” VPA, modification of the consumption model, introducing a weak Type III functional feeding response, formalizing the derivation of selectivity parameters from diet data, altering the size-selectivity model, and including predators without age-structured assessment data. These additions allow a clearer definition of the input parameters used to model diets and consumption rates and improve the MSVPA equations to reflect processes controlling feeding and predation rates.

1.1.1 Single-species VPA formulation

Implementation of multiple SSVPA models allows greater flexibility in model construction to address particular data availability and the most appropriate assessment approach for each modeled species. Several forms of SSVPA are implemented in the MSVPA-X program. Some of these were included specifically to match previous assessment approaches for species considered in this application. However, for this application, all species use the XSA method.

The XSA (Shepherd, 1999) is a tuned VPA method that provides solutions for mortality rates in incomplete cohorts based upon multiple fishery-dependent and -independent abundance indices. The approach is related to the ADAPT VPA currently applied in many ASMFC single-species stock assessments. However, the ADAPT method requires extensive model building and minimization routines, resulting in a thorough statistical treatment that generally requires considerable analytical expertise and judgments of input parameters to develop the most appropriate model. While XSA does not reflect the full statistical approach of ADAPT methodology and does not require as intensive computational or model-building demands, it retains a similar theoretical basis and provides similar results. The XSA approach is therefore preferred within the MSVPA-X framework because it provides an SSVPA assessment tuned to external abundance indices that is relatively simple to execute.

The MSVPA-X implementation of XSA is identical to that described in Darby and Flatman (1994). The XSA approach includes a method described as “shrinkage to the mean F ” to constrain estimates of fishery mortality rate in terminal age classes and years of the catch matrix. In general, applications not incorporating shrinkage result in unconstrained estimates of F in the last years and ages of the assessment and prevent convergence of the model. Estimates of terminal fishing mortality rates may be sensitive to values of shrinkage parameters, and the model estimates of F for a range of these parameters should be explored when implementing the XSA approach. Individual parameter descriptions are included below. For more details, please see Darby and Flatman (1994).

CV for Shrinkage Mean: This parameter controls the weighting applied to the shrinkage mean F . Large values result in lower weighting of the mean and therefore less constraint of terminal F values to the time series average F .

Number of Years for the Shrinkage Mean: In the last year of the catch matrix, estimates of F on each age class are constrained by the average F calculated over the previous N years of the assessment as determined by this parameter value.

Number of Ages for the Shrinkage Mean: In the terminal age class of each year of the catch matrix, the estimate of F on the last true age class is constrained by the average F over the previous N age classes as determined by this parameter value.

Downweight Early Years: In the calculation of shrinkage means and terminal F estimates, early years of the catch matrix are “downweighted” on the assumption that catchabilities and average F estimates in recent years are more similar to those of the terminal years. It is highly recommended that downweighting be applied when shrinkage is employed.

Select Weighting Method: Linear, Bisquare, and Tricubic downweighting can be applied in increasing order of the strength of the downweighting function. In the tricubic downweighting, early years of the time series have the least influence on estimates of terminal F .

1.1.2 Predator Consumption Model

Predation mortalities in the ICES MSVPA approach are calculated based upon a simplified feeding model developed directly from the approach described by Andersen and Ursin (1977) formulated as discrete expressions standardized to a duration of one year. Total food consumption rates in biomass for a given predator species and age class is expressed as a simple ratio of total predator weight:

$$(1.1) \quad R_{ia} = v_{ia} w_{ia}$$

where v_{ia} is a constant ratio (biomass prey / biomass body weight) and w_{ia} is predator body weight. This constant ratio therefore does not reflect effects of food availability on feeding rates or temperature effects on predator metabolism.

In reality, food consumption rates in fish can vary strongly, particularly between seasons as a function of food availability, changing temperatures, and metabolic demands. To account for these processes, a somewhat more detailed consumption model was implemented using the Elliot and Persson (1978) evacuation rate approach within the MSVPA-X equations and including a modified functional relationship between food availability and predator consumption rates.

The daily ration, R , calculated in equation 1.1 is replaced with the consumption rate (in biomass) for predator i , age class a . Total consumption in year, y , for a predator during a given season, s , is then:

$$(1.2) \quad C_{ys}^{ia} = 24E_s^{ia} \cdot \overline{SC_s^{ia}} \cdot D_s \cdot w_{ys}^{ia} \cdot \overline{N_{ys}^{ia}},$$

where SC_s is the mean stomach contents weight relative to predator body weight in a season, D_s is the number of days in the season, w_{ys} is the average weight-at-age for the predator species, and N_{ys} is the abundance of the predator age class during the time interval. The evacuation rate (hr^{-1}) is given as:

$$(1.3) \quad E_s^{ia} = \alpha_{ia} \exp(\beta_{ia} \cdot \text{temp}_s),$$

with temp equal to seasonal temperature ($^{\circ}\text{C}$) and α and β are fitted parameters based upon laboratory feeding experiments, field studies, or other sources (Elliot and Persson 1978, Durbin *et al.* 1983). The evacuation rate (1.3) reflects the temperature dependent metabolic rates of the predator, and requires that the MSVPA-X equations be seasonally resolved. Whereas the mean stomach contents weight reflects both the size of the predator and encounter rates with suitable prey items. The evacuation rate approach for calculating predator consumption was previously implemented within MSVPA by Tsou and Collie (2001).

1.1.3 Functional Feeding Response

The standard MSVPA formulation assumes that predator feeding rates are independent of prey availability, resulting in a Holling type II predator-prey feeding response (Magnusson, 1995). Type II feeding responses result in depensatory dynamics in predation mortality rates. The estimated predation mortality rate on a given prey item will increase exponentially at low prey biomasses, thus creating a “predation pit” that can result in unrealistic model dynamics such as prey extinction due to predation. In contrast, type III functional responses are compensatory in nature in that the feeding rate on a particular prey item will decline at low prey abundances, and hence predation mortality pressure is released. To avoid the unrealistic dynamics resulting from the type II feeding relationship, the MSVPA-X implements a weak type III feeding response by modifying the consumption equation (Equation 1.2) to incorporate a logarithmic relationship between food availability (measured as total suitable prey biomass) and the amount of prey consumed by a predator.

Given an average stomach contents across years for predator i , age class a , in season s , $\overline{SC_s^{ia}}$, as an input to the model, the stomach contents corrected for food availability in a given year, y , is calculated as:

$$(1.4) \quad SC_{ys}^{ia} = \overline{SC_s^{ia}} + \log\left(\frac{SB_{ys}^{ia}}{\overline{SB_s^{ia}}}\right) \cdot \overline{SC_s^{ia}}$$

where SB is the total suitable biomass available to the predator. The proportional stomach content weight calculated by equation 1.4 is substituted for the average value in equation 1.2 to calculate total consumption for a predator age, year, and season. The corrected stomach contents are further constrained to be $> 10\%$ of the input average value and less than three times the input

value. These constraints avoid unrealistically small or large predator feeding rates in very extreme cases. The resulting consumption rate as a function of food availability is shown in Figure D.1.

In Figure D.1, the suitable biomass of a particular prey type is varied across a broad range while that of other prey types is held constant. The standard type II feeding response model results in an asymptote of total consumption with increasing prey biomass. In contrast, the model including a correction for food availability results in increasing predator consumption with increasing prey biomass and reduced consumption at lower prey availability relative to the standard model. The resulting predation mortality rates as a function of food availability are shown in Figure D.2.

Through most of the range of prey biomass, the two approaches result in similar predation mortality rates. However, at low prey biomasses, the standard type II model results in exponentially increasing predation mortality. The alternative model has a slower rate of increasing predation mortality, and there is a point at which predation mortality declines with further decreases in prey biomass. This approach avoids the compensatory dynamics that can result in unrealistic model predictions under the standard model.

1.1.4 Feeding Selectivity Parameters

To calculate the composition of prey, a feeding model is employed that includes a “suitability index” for a given prey species, j , and age class, b , for predator species, i , and age class, a :

$$(1.5) \quad S_{jb}^{ia} = O_j^i \cdot A_j^i \cdot B_{jb}^{ia},$$

where O is a spatial overlap index, A is a measure of “general vulnerability”, and B reflects size selection (Gislason and Helgason, 1985). Each of these terms ranges between 0 and 1. In the initial formulation of the approach, the general vulnerability index was given a somewhat arbitrary definition and was taken to reflect vertical overlap between predator and prey species. The spatial overlap index was likewise developed to express the proportion of predator and prey populations that overlapped horizontally and interact with one another. However, in the original formulation these terms are not explicitly defined and were often chosen in an *ad hoc* manner. Therefore, the approach has relied upon the presence of extensive diet information for at least one year to “tune” the selectivity parameters. The MSVPA-X model more explicitly defines the parameters entering the basic selectivity equation rather than relying on the somewhat circular approach of back-calculating selectivities through an additional iteration incorporating diet information that may not be available for all species and age classes.

1.1.4.1 Spatial Overlap (O)

Williamson (1993) separated the predation components into what he termed “density risk” and “prey vulnerability”. Density risk reflects the relative encounter rate of predators and prey driven by spatial overlap, while prey vulnerability reflects the combined probabilities of attack, capture, and ingestion. Density risk is expressed as a product of predator abundance and a spatial overlap

index. In this case, a similarity index is calculated based upon the relative abundance of predators and prey in defined areas within the model's spatial domain:

$$(1.6) \quad O_{ij} = 1 - 0.5 \sum_z |p_{iz} - p_{jz}|,$$

where p_{iz} is the abundance of each predator or prey in each of z spatial cells. The index ranges between 0 and 1. The spatial overlap index between predator and prey types can be calculated based upon available data across a relevant level of spatial resolution and scope. Likewise, because there are seasonal differences in spatial distribution, the spatial overlap value can be seasonally resolved in the MSVPA-X implementation. Spatial overlap indices should be developed on a seasonal basis across the entire range of the model area. Potential sources of data include fishery-independent surveys, tagging studies, and fishery landings data.

1.1.4.2 Type Preference (A)

The MSVPA-X follows the general approach of the standard MSVPA and resolves feeding selectivity into two components reflecting “type” and “size” selection. However, the model follows the definitions of Chesson's (1983) electivity index in parameterizing these as opposed to the *ad hoc* definitions used in the original implementation of the MSVPA. Chesson's index is a relative index ranging from 0 to 1 that reflects the probability of selection of food type i given the presence of m food types in the environment:

$$(1.7) \quad P_i = \frac{\alpha_i n_i}{\sum_{j=1}^m n_j},$$

where n is the abundance of a given prey type in the environment. The selectivity index, α_i , is the amount of food type i in the diet relative to the amount in the environment scaled so that the sum of all α_i is 1. This index expresses the expected diet composition of the predator if all prey were equally available in the environment (Chesson, 1983) and is calculated as:

$$(1.8) \quad \alpha_i = \frac{r_i / n_i}{\sum_{j=1}^m r_j / n_j}.$$

Under a case of random selection (no preference), $\alpha_i = 1/m$. This is equivalent to the selectivities form solved for in the final iteration loop of the standard MSVPA, which combines spatial overlap and size selection into a single index.

The MSVPA-X model resolves feeding selectivity, and resulting indices, into two components of type and size selection. Type selection reflects preference for a particular species relative to all others based upon ease of capture, energy content, or other factors that result in a preferred prey type. Size selection reflects primarily capture and ingestion probabilities and is a function of relative prey to predator length as opposed to weight in the standard MSVPA equations. This

formulation explicitly assumes that type selection is independent of prey size. This is consistent with several examples in the literature that suggest consistent type selection for a range of prey sizes. For example, in juvenile bluefish, fish prey were preferred over shrimp prey across a range of sizes for each type (Juanes *et al.*, 2001). To reflect changing type preferences across predator ontogeny, type selection is entered for each predator age class in the MSVPA-X implementation.

1.1.4.3 Deriving Ranked Type Preferences

Type selection is entered as a proportional rank index to further reduce the data demands. Thus, for each prey type (or species), a preference rank is assigned for a given predator age class. If a prey species is not consumed by that predator age class, then it is given a rank of zero. The proportional inverse rank is calculated as:

$$(1.9) \quad A_i = \frac{m - r_i}{\sum_{j=1}^m r_j},$$

where m is the number of prey species and r_i is the preference rank for each species. The resulting proportional index is equivalent to the expected diet composition for the predator given equal prey abundances and equal prey sizes. If there is no type selection, then all prey species are given equal, tied ranks.

Developing prey type selection rankings requires reviewing available diet information for each predator. Ideally, diet studies would be available over a broad geographic area and encompass the same temporal resolution (seasons) and scale (duration) of the model runs. A suggested empirical approach for developing these input parameters from available data is as follows:

Step 1: Obtain all raw diet data and information on the scales and sampling methods of the individual studies.

Step 2: Weight individual studies by length of time series, geographical coverage, and the number of samples. Also, diet studies in which the abundance of a single prey item dominates should be examined closely. Assigning a weighting factor for spatial, temporal, and sample size differences will attempt to account for local abundance issues associated with the particular diet study.

Step 3: Generate an average seasonal diet matrix over temporal and spatial range of model to separate effect of differences in abundance.

Step 4: Develop a relative abundance/biomass matrix by season for all prey species. This would aid both when considering the influence of abundance of prey affecting selectivity and testing the difference between generalist feeding and choice of prey type.

Step 5: Calculate a electivity matrix based on diet and abundance information to develop prey type ranking.

1.1.4.4 Size Preference (B)

The final component of the feeding selectivity relationship is size selectivity. Again, this is framed in terms of Chesson's index such that the size selection parameters across the size range of the prey sum to 1 and the selection parameter for a certain sized prey, l , reflects the proportion of the predator's diet that would be comprised of prey items of that size independent of type selectivity and relative abundance. The original equation from the ICES MSVPA for size selectivity does not follow this formulation and instead uses a weight ratio to determine selection for a particular prey item. The vast majority of the feeding literature indicates that the relative length of the prey is the more pertinent measure, presumably due to factors such as gape width limitations and, relative swimming speed. For example, predator-prey length ratios had a significant effect on prey capture probabilities for juvenile bluefish (Scharf *et al.*, 1998). In general, this effect results in a dome-shaped relationship between predator-prey length ratios and the capture success and is often reflected as a unimodal distribution of prey in the diets.

To effectively model this pattern, the MSVPA-X model takes a similar approach to that described in Tsou and Collie (2001) by using a flexible unimodal function to describe the relationship between prey size and the proportion of the prey in the diet. However, the MSVPA-X model uses the incomplete beta integral. The form of this function is more consistent with the formulation of Chesson's selectivity index as it integrates to 1 over the domain of predator to prey ratios being considered. The size selection index for a prey of a particular size thus corresponds to the predicted proportion of prey of that size in the predator's diet.

The beta integral is given as:

$$(1.10) \quad B(\alpha, \beta) = \int_0^1 t^{\alpha-1} (1-t)^{\beta-1} dt$$

and this is related to the incomplete beta integral as:

$$(1.11) \quad I(z; \alpha, \beta) = \int_0^z t^{\alpha-1} (1-t)^{\beta-1} dt / B(\alpha, \beta).$$

The size selection coefficient over some size range between x_{\min} and x_{\max} is calculated as:

$$(1.12) \quad S(\alpha, \beta) = I(x_{\max}; \alpha, \beta) - I(x_{\min}; \alpha, \beta).$$

In this case, x is the prey to predator length ratio. The incomplete beta function can be fit to data on the length distribution of fish prey in stomach data by maximum likelihood estimation and goodness of fit assessed with chi-square tests to derive values for the coefficients α and β . This assumes that length distribution of prey in the diet reflects selection rather than availability, which may be a reasonable assumption in data sets of broad spatial and temporal scope. Example size selection curves for different age ranges of a fish predator using the beta function are shown in Figure D.3.

To develop size selectivity parameters, the following procedure is suggested:

Step 1: Compile data for relative length-frequency of prey items in diet by species.

Step 2: These studies should be weighted on the length of study (number of years), area covered, and number of samples to obtain average picture of prey length consumed.

Step 3: Based upon these weighted average curves, fit the beta integral to available data to derive parameters for input into the model. An Excel spreadsheet function is provided with the program distribution to allow fitting of these parameters based upon available data.

1.1.4.5 Biomass Predators

One potential limitation of the previous application is that all predator species must be explicitly modeled within the standard MSVPA and must therefore have age-structured catch data and meet other assumptions of the model. While there is a capability to include “other prey” that do not correspond to these assumptions, there is no mechanism to incorporate removals by other predators for which only biomass or abundance information is available. Examples of such sources include fish species where age-structured models are unavailable or inappropriate and for species such as birds and marine mammals for which age-structured models are typically impractical. An approach to incorporate “biomass predators” that may have significant predatory impacts has been implemented in the model to overcome this limitation. These predator populations are not explicitly modeled; however, biomass and feeding information are incorporated to calculate the predation mortality rates due to these predators on explicitly modeled prey species.

Inputs for biomass predators include total predator biomass across the time frame of the model, the proportion of the predator biomass in user specified size intervals, consumption parameters, mean stomach contents, and spatial overlap and type preference parameters similar to those for standard species. In addition, one must specify the size selectivity parameters (equation 1.10; α and β) and the size range of the predator. Size selection by other predators is implemented in a similar manner to that for other prey. Size selectivity for a particular sized prey is integrated across the size range for a given size class of biomass predator:

$$(1.13) \ S = \int_{l_{\min}}^{l_{\max}} S(x/l; \alpha, \beta) dl.$$

Where l is the predator length, x is the prey length, and the function in the integral is the size selectivity function (equation 1.12). This is essentially an average value for the selectivity parameter over the range of the predator size class. Aside from this modification, the biomass predators are treated identically to other species when calculating suitable prey biomass, consumption rates, and diets.

1.2 CALCULATION OF PREDATION MORTALITY RATE (M2)

In addition to standard prey, an additional prey type is included in the MSVPA formulation to account for other fish prey and system biomass that is available to the predator species. As with

explicitly included fish prey (i.e., menhaden), selectivity for “other prey” is calculated using equation 1.5. However, the size selection must be calculated based upon an input size distribution for the other prey biomass. The size-selectivity function is then integrated over the size range of the other prey:

$$(1.14) \quad S_x^{ia} = O_x^i \cdot A_x^i \int B_x^{ia} \cdot BM(l)_x dl.$$

The total food available for a given predator species and age class, or “suitable biomass” is expressed as:

$$(1.15) \quad SB^{ia} = \sum_x S_x^{ia} B_x + \sum_j \sum_b S_{jb}^{ia} \cdot w_{jb} \cdot \overline{N_{jb}},$$

and,

$$SB_{jb}^{ia} = A_j^{ia} \cdot B_{jb}^{ia} \cdot O_j^{ia} \cdot w_{jb} \cdot \overline{N_{jb}}$$

which is the weighted sum of biomass, B_x , across all “other prey” types, and the sum of prey biomass ($w_{jb} \cdot N_{jb}$) across all prey species, j , and age classes, b . It is important to note that the relevant abundance is the average number of prey available during the time interval given as:

$$(1.16) \quad \overline{N_{jb}} = N(0)_{jb} \cdot \frac{\exp(-\alpha Z) - \exp(-\beta Z)}{(\beta - \alpha)Z},$$

where α and β are the beginning and end of the time period being considered expressed as a proportion of a year.

The biomass of a particular prey consumed by a predator is the product of total consumption by the predator and the proportion of total suitable biomass represented by that prey type:

$$(1.17) \quad P_{jb}^{ia} = \frac{SB_{jb}^{ia}}{S^{ia}} \cdot C^{ia},$$

and, the predation mortality rate due to the predator is the ratio of these removals to the average abundance of the prey during the time interval:

$$(1.18) \quad M2_{jb}^{ia} = \frac{P_{jb}^{ia}}{w_{jb} \overline{N_{jb}}}.$$

Total predation mortality rate for a given prey species and age class is finally the sum across all predators:

$$(1.19) \quad M2_{jb} = \sum_i \sum_a M2_{jb}^{ia}.$$

The model is initiated with user-entered, fixed values of M2 for each species. The SSVPA's are run and M2 values are calculated using the equations above based upon calculated biomasses and selectivity parameter inputs. The M2 values are then used in successive iterations of the model which are repeated until the M2 values do not change appreciably between iterations. The iteration loop implemented in the MSVPA-X application is shown in D.4.

1.3 MULTISPECIES FORECAST MODEL

MSVPA-X includes a forecast model that allows exploring potential effects of management scenarios. The forecast model includes the feeding response and consumption equations used in the historical model. A given application of a forecast model is based upon a reference MSVPA-X implemented in the project file. The forecast model is built upon the basic age-structured population model:

$$(1.20) \quad N_{t+1} = N_t \exp[-(F + M1 + M2)],$$

Population biomass is then simply:

$$(1.21) \quad B_t = N_t w_t$$

where w_t is the weight of an individual at time t . Thus, given an initial population size (N_0), fishing mortality rate (F), and other natural mortality rate ($M1$) it is necessary to calculate both individual weight at time t and M2 to project the population forward.

As shown previously, predation mortality rate is a function of prey selection, predator biomass, predator weight, and prey abundance. However, to calculate M2 for a given season using the standard MSVPA-X equations, one must know the average prey and predator biomass during the season, which require estimates for the total mortality rate (Z), and hence M2, experienced during the season. The projection model is resolved to a daily time step to avoid this problem.

At each daily time step in a given season, the size and weight of predators and prey species are calculated from input growth parameters. These terms are used to calculate feeding selectivity parameters, and the total suitable prey biomass for the daily time step is calculated based upon biomasses at the beginning of the day. Predator consumption is modeled as in the historical MSVPA-X approach. The correction for food availability is relative to the historical time series average of total suitable prey biomass from a reference MSVPA-X run.

The amount of each prey type consumed is then converted into a daily mortality rate from the total biomass consumed. This is accomplished first by converting biomass consumed to numbers consumed by dividing by prey weight. The predation mortality rate during the daily time step is then solved iteratively for total mortality, Z , using a solution of the standard catch equation:

$$(1.22) \frac{C}{N} = \frac{M2}{Z}(1 - \exp(-Z)),$$

where N is prey abundance at the beginning of the time step, C is the number consumed during the time step by all predators, and $Z = F + M1 + M2$ where daily values for F and $M1$ are given. The calculated mortality rates are thus used to project the predator and prey populations forward to the next day.

The model is initialized to a selected year of the reference MSVPA-X historical run. Model outputs include seasonal estimates of predation mortality, predator and prey population sizes in numbers and biomass, fisheries yields (given F), seasonal average predator diets, total seasonal consumption, and seasonal predator size and weight-at-age. The projection model is run for each age class of each predator and prey population on an annual basis, starting from the population abundance at age estimated in the initial year of the projection. It is necessary to include a stock-recruit relationship to calculate the initial abundance of age-0 fish at the beginning of each year. This is accomplished by calculating the spawning stock biomass for each year based upon input maturity information and a stock-recruit relationship that is fit based on data from the MSVPA-X runs and selected by the user. The structure of the forecast model implementation is shown in Figure D.5. Four different stock-recruitment models are provided as options in the forecast model:

1.3.1 Ricker Stock-Recruit Relationship

$$(1.23) R = aS \exp(-bS)$$

This is the standard Ricker Stock-Recruit model that includes strong compensatory dynamics resulting in low recruitment success at large stock sizes. The application fits a linear transformation of the model using least-squares regression and displays model fit diagnostics.

1.3.2 Beverton-Holt Relationship

$$(1.24) R = \frac{aS}{b + S}$$

A linear transformation of the standard Beverton-Holt model is also fit using least squares regression.

1.3.3 Random from Quartiles

In cases where there is no clear relationship between spawning stock biomass (SSB) and recruitment, it may be appropriate to use a more flexible, stochastic relationship. The “random from quartiles” approach sorts SSB values from the time series into quartiles and determines the minimum and maximum recruitment observed within each SSB quartile. During the projection model, the calculated SSB is compared to the observed quartile ranges, and a value for

recruitment is randomly selected from a uniform distribution ranging between the minimum and maximum recruitment for the appropriate quartile. A weak dependence between SSB and recruitment is maintained with this approach if one exists. Recruitment values are constrained to be between the minimum and maximum values of those observed during the reference MSVPA-X run.

1.3.4 Shepherd Flexible

Shepherd (1982) proposed an alternative stock-recruit relationship that has a more flexible level of compensatory dynamics than the standard Ricker curve. The Shepherd model contains a third term that determines the strength of compensatory declines in recruitment at large stock sizes.

$$(1.25) \quad R = \frac{aS}{1 + (S/B)^\gamma}$$

The model is non-linear, and therefore it is more difficult to develop a unique and reliable model fit, particularly when there is a large amount of variation in the data.

CHAPTER 2: DATA INPUT AND MODEL PARAMETERIZATION

2.0 SINGLE-SPECIES ASSESSMENT DATA

This configuration of the MSVPA-X model uses data from each single-species assessment completed in 2002 and 2003, permitting a multispecies analysis through 2002. Below is a summary table of single species stock assessment models used in the MSVPA-X formulation and the current assessment model used for each species.

Species	Assessment model used in MSVPA-X	2002/2003 Assessment model	Current assessment model (2005)
Menhaden	Extended Survivors Analysis (XSA)	Forward Projecting Age Structured model	Forward Projecting Age Structured model
Striped Bass	XSA	ADAPT VPA	ADAPT VPA
Bluefish	Biomass Input	Biomass Dynamic model (ASPIC)	Statistical Catch-at-Age model (ASAP)
Weakfish	XSA	ADAPT VPA	Relative F model

2.1 ATLANTIC MENHADEN

2.1.1 Summary of Fishery and Assessment

The Atlantic menhaden fishery consists largely of purse seine vessels targeting fish for two distinct uses. The reduction fishery typically focuses on relatively young, small fish in the estuaries and coastal waters along the U.S. Atlantic coast, particularly in Chesapeake Bay. Menhaden captured in this fishery are processed for sale as fish meal or fish oil. Purse seine vessels are also the primary component of a fishery that targets larger fish for sale as bait for crab pot and other fishing operations. There are additional small directed and bycatch based gillnet fisheries for menhaden in most states (reviewed in ASMFC, 2004a).

The reduction component of the fishery is intensively monitored, with both catch-at-age and effort data available since 1955. Fishery information on the bait component is less reliable and the catch-at-age matrix from commercial bait landings was used for 1985-2002. Biological sampling for age and size data at the reduction plants has been in place throughout the time series, but sampling of the bait fishery catches is less reliable prior to 1988. Annual size-at-age and length-weight regressions are available from 1955 to the present.

Prior to 2003, the Atlantic menhaden stock assessment used a Murphy Virtual Population Analysis approach. Terminal fishing mortality rates were estimated by a standard catch curve analysis. Population sizes in the last year of the assessment were estimated using a separable

VPA based upon the last 3-7 years of the catch-at-age matrix (Vaughn *et al.*, 2002). However, during the most recent stock assessments, a forward projecting age-structured model was applied to the Atlantic menhaden stock (ASMFC, 2004a). The model incorporated two indices of abundance: an aggregated coast wide age-0 index and a CPUE index for pound net catches. This approach also allows separate treatment of the bait and reduction fisheries, which is particularly appropriate given the different selectivity of the fisheries (reviewed in ASMFC, 2004a).

The newly applied forward-projection model results in similar trends in the Atlantic menhaden population to the previous assessment approach, though there are changes in the absolute estimates of both fishery and natural mortality rates, as well as population sizes. The stock assessment indicates that Atlantic menhaden spawning stock biomass and population fecundity are currently high relative to the population median during the last two decades, though considerably lower than peaks during the late 1950s and early 1960s. The number of recruits (age-0 and age-1) has generally been declining since reaching a peak during the early 1980s. The 2002 estimate of recruits to age-1 falls below the 25th percentile of the time series; however, this recent estimate is highly uncertain. Based primarily upon current estimates of fishing mortality rate and spawning potential, the stock assessment concludes that this population is currently not overfished.

2.1.2 Fishery Catch-at-Age

Time series for predator catch-at-age matrices are restricted to the period from 1982-2002. Thus, the MSVPA-X model uses the Atlantic menhaden catch-at-age data for this period. Unlike the single-species assessment, it is not currently possible to model selectivity for the reduction and bait fisheries separately in the MSPVA-X approach. Thus, a combined catch-at-age matrix is employed including both bait and reduction fishery landings from 1985-2002. Prior to 1985, only reduction landings are included in the catch data. The method for deriving catch data is detailed in ASMFC (2004a), and data are shown in Table D.1.

2.1.3 Fishery-Independent and Dependent Tuning Indices

A fishery-independent coast wide juvenile (age-0) index is available for Atlantic menhaden based upon five seine surveys conducted between North Carolina and Rhode Island. Individual state seine survey indices are derived using a lognormal generalized linear model (GLM). Correlations between surveys are then evaluated to combine individual regional surveys; for example the Virginia and Maryland surveys are highly correlated and reflect trends in Chesapeake Bay. The regional indices are then combined using an average weighting based area of the associated drainage basins. The resultant coast wide index is used as a tuning index for age-0 abundance in the single-species assessment approach used in the MSVPA-X model (Table D.2).

The forward-projection stock assessment model also uses a biomass index based upon CPUE of Potomac River pound net catches. The pound net index reflects total biomass of primarily age 1-3 Atlantic menhaden. The formulation of the MSVPA-X model requires an age-disaggregated index of abundance as opposed to biomass. Based upon the age selection model applied in the forward-projection approach and estimated weights-at-age, the CPUE (biomass) index is

converted to an age-specific index of abundance (numbers) for age classes 1-3 (Table D.3). These age-specific indices are used as tuning indices for adult abundance in the MSVPA-X application.

2.1.4 Age and Growth

Size and weight-at-age derived from von Bertalanffy growth curve parameters and length-weight regression parameters are available annually since 1955 based on commercial fishery sampling (ASMFC, 2004a). However, there is a high degree of interannual variation in predicted sizes and weights-at-age, particularly in the younger age classes. In order to reduce this variability, average size and weight parameters are calculated in five-year intervals from 1982-2002. These average parameters are used to develop size and weight-at-age matrices for use in the MSVPA-X application (Table D.4, Table D.5). In the single-species assessment, the weight-at-age-0 is actually represented by age = 0.75 menhaden because fishery catches do not occur until late in the year (ASMFC, 2004a).

2.1.5 Single-Species VPA Formulation

In the MSVPA-X application, XSA is used as the single-species assessment model for Atlantic menhaden because it allows including the coast wide juvenile index and the age disaggregated pound net CPUE index as tuning indices and is thus consistent with the approach used in the forward-projection assessment model. A range of XSA options were evaluated to explore the sensitivity of predicted fishing mortality rates to values of shrinkage parameters including the number of years and ages used to calculate terminal fishing mortality rates. Estimated fishing mortality on the last age class was sensitive to the number of age classes used to calculate terminal F (Figure D.6). Four age classes were used to calculate the shrinkage mean to preserve a dome-shaped fishery selection curve to be consistent with the findings of the forward-projection model. The XSA model estimated higher fishing mortality rates on older age classes than the forward-projection approach (Figure D.7). This is likely due to the fact that the reduction and bait fisheries cannot be separately analyzed in the XSA formulation. However, the trends in fishing mortality rates were similar in the two assessment approaches.

The two approaches give similar trends and estimates of total abundance when the same natural mortality vector is applied to each model. For comparison to the assessment results, the natural mortality vector estimated by the forward-projection model was applied to the XSA (age-0 $M = 4.31$, age-1 $M = 0.98$, age-2 $M = 0.56$, age-3+ $M = 0.55$). The resulting XSA runs gave very similar results to the forward-projection model for ages 0 and 1. However, the abundance of older age classes was underestimated by the XSA in comparison to the forward-projection results, consistent with higher estimates of fishery mortality rates on these age classes. The overall magnitude and trends in abundance were similar between the two approaches (Figure D.8).

In the base MSVPA-X run, the XSA model using four age classes and two years to calculate the “shrinkage” mean was applied. The base natural mortality rate (M_1) was set at 0.4 for all age classes.

The Atlantic menhaden stock assessment is scheduled to be updated in 2006 using the forward-projection assessment model.

2.2 STRIPED BASS

2.2.1 Summary of Fishery and Assessment

Striped bass commercial and recreational fisheries occur in nearshore coastal waters, estuaries, and tributaries along the U.S. Atlantic coast, particularly north of North Carolina and in the main-stem and tributaries of the Chesapeake Bay. The stock suffered very high fishing mortality and severe declines in abundance and spawning stock biomass during the late-1970s and early 1980s. Reduced fishery mortality rates during the 1980s and 1990s led to recovery of the stock. Abundance and biomass are currently high. Fishing mortality rates are below target levels for ages 4-11 fish, but exceed management targets for older age classes (ages 8-11; ASMFC, 2003).

The striped bass stock assessment is based upon catch-at-age based VPA using the ADAPT methodology and tag-recovery survival estimation. The VPA analysis is the primary tool used to provide mixed-stock estimates of fishing mortality rate. Catch-at-age matrices for the ADAPT methodology are derived from sampling of the commercial catch. Corrections are made for estimated levels of commercial discard mortality using tag-recovery rates for specific gear types and the spatial distribution of commercial fishing effort (ASMFC, 2003). Recreational harvest and discards derived from MRFSS data following standard methodologies. Length-frequency sampling was converted to catch-at-age by applying state-specific age-length keys (ASMFC, 2003).

Age-length keys for all states are derived from scales. However, there is significant concern over the accuracy of age assignments for fish over age-12 (ASMFC, 2003). To evaluate sensitivity to potential ageing errors, the most recent stock assessment evaluated the effects of designating different “plus-group” configurations including 12+, 13+, 14+, and 15+ categories in the catch-at-age matrix. Based upon this analysis, the 13+ age class was chosen as providing the most appropriate model formulation. In contrast, all previous year assessments applied a 15+ age class. Uncertainty in ageing of older fish remains a considerable challenge in the assessment of the striped bass stock.

For this analysis, we developed XSA runs for direct comparison to the 13+ ADAPT VPA used in the striped bass stock assessment. Numerous age-specific fishery-independent surveys are used as tuning indices for these approaches. The input data and configuration for the XSA and ADAPT approaches are nearly identical, allowing direct comparison of model results.

2.2.2 Fishery Catch-at-age

A catch-at-age matrix is available for 1982-2002. Catch data include commercial and recreational harvest and discard losses; complete details are included in the stock assessment report (ASMFC, 2003; Table D.6).

2.2.3 Fishery-Independent Surveys

Numerous abundance indices are available from fishery-independent and dependent surveys. Age-specific fishery-independent surveys include the Virginia pound net, Maryland gillnet survey, Connecticut trawl survey, New York ocean haul seine survey, New Jersey trawl index, Delaware trawl survey, and the NEFSC spring bottom trawl survey. Fishery-dependent indices include Massachusetts commercial CPUE, Hudson River shad fishery bycatch, and Connecticut volunteer angler CPUE. Juvenile surveys conducted in each state provide YOY indices from Maryland, Virginia, New York, and New Jersey. Yearling indices are available from New York and New Jersey.

The striped bass stock assessment subcommittee eliminates the Maryland spawning stock biomass age-2 index, the NEFSC trawl survey ages 12-15, and the Virginia Pound Net survey based on sampling and ageing concerns. The XSA analysis uses the same suite of indices as the ADAPT analysis, with the exception of age aggregated indices that cannot be used in the current implementation of the XSA.

2.2.4 Age and Growth

Striped bass weight-at-age is derived from several state sampling programs of commercial and recreational catch. Mean weight-at-age in the population is calculated as an average of state values weighted by the commercial catch. The weight-at-age matrix for 1982-1996 was developed for the 1997 stock assessment (NEFSC, 1998), and weights developed for 1997 were applied to 1998 and 1999. Weight-at-age for 2000-2002 were recently updated and applied in the most recent assessment (ASMFC, 2003).

Size-at-age is derived from state specific age-length keys. Seasonal average length-at-age for each state is calculated based upon available data. These state-specific estimates are then used to develop an average length-at-age vector by fitting a von Bertalanffy growth curve.

Due to uncertainties in ageing and questions about the representative nature of the annual weights-at-age derived in the striped bass assessment, the average weight-at-age is used in the base run of the MSVPA-X. Likewise, since there is no information on interannual variation in striped bass length, a single size-at-age vector is applied in the current analysis (Table D.7).

2.2.5 Single-Species VPA

Extended survivors analysis (XSA) is used as the single-species VPA model for striped bass in this application. The XSA approach is similar to the ADAPT methodology in that it utilizes tuning indices in the estimation procedures for fishery mortality rates. The tuning index data used in the 2003 striped bass stock assessment are used in the XSA, with the exception of age-aggregated and biomass indices. As in the ADAPT assessment, a 13+ age class is used and natural mortality set at 0.15 (ASMFC, 2003).

A series of XSA evaluation runs were conducted to evaluate sensitivity to XSA parameters and to compare results to the ADAPT assessment. Estimation of fishery mortality rates on older age

classes was sensitive to the selection of the number of age classes used to calculate the shrinkage mean F (Figure D.9). Calculating the shrinkage mean using 4 age classes most closely approximated the ADAPT results and will be used in the MSVPA-X application. The estimates of F were insensitive to other XSA parameters including the number of years used to calculate the shrinkage mean F in the last year. Trends in F were qualitatively similar for age classes 3-8 and 8-11 for the two approaches (Figure D.10). There was a tendency for the XSA to estimate slightly higher values of F relative to the ADAPT approach for older age classes during the last years of the assessment (Figure D.11). However, the selection curve and average F at-age were comparable between the two models.

The time series of estimated recruit abundance differed significantly in the last two years of the time series with ADAPT estimating much higher age-1 abundance during 2001 and 2002 compared to XSA (Figure D.11). For both assessment approaches, estimates of F and abundance for pre-recruit age classes is highly uncertain, so it is difficult to evaluate which model provides the “better” assessment. The trends and estimates of abundance for the remaining age classes are similar between the two approaches, though there is a tendency for the XSA to underestimate abundance relative to the ADAPT model (Figure D.11).

The striped bass stock assessment is updated annually and the next benchmark stock assessment is scheduled for 2007.

2.3 WEAKFISH

2.3.1 Summary of Fishery and Assessment

Weakfish are harvested commercially and recreationally along the U.S. Atlantic coast and in estuaries from Florida to the southern Gulf of Maine. Adult fish are harvested in offshore waters off of Virginia and North Carolina by gillnet and trawls. During spring and summer, gillnets and trawls are used to harvest fish in more northern coastal waters, and primarily gillnets are used in estuarine waters along the U.S. Atlantic coast. Recreational catch is concentrated in estuarine waters in the mid-Atlantic; however, there are significant recent recreational catches in southern New England states (Kahn, 2002a).

The weakfish stock biomass was generally low throughout the 1980s into the early 1990s. Fisheries regulations were put into place to restore the stock in the mid-1990s (Amendment 3 to the Interstate Fishery Management Plan for Weakfish), and estimated stock abundance and biomass has been generally increasing since at least 1990. The estimate of fishing mortality rate in the terminal year (2000) was below both the target and threshold values of F under the current FMP (Kahn, 2002a).

Kahn (2002a) applied the ADAPT VPA approach to a catch-at-age matrix derived from commercial and recreational catches through 2000. There is significant concern with the very low estimates of terminal fishing mortality and associated large population size estimates. Retrospective analyses of the ADAPT assessment indicate that the terminal F estimate may be underestimated by 100% (Kahn, 2002a). Additional concerns include the relatively limited geographic scope of biological sampling of the commercial catch, lack of data on commercial

discard mortality, and lack of information on recreational discards. The weakfish stock was assessed in 2004, but confounding signals from fishery-independent and fishery-dependent data prevented the ASMFC Weakfish Technical Committee from completing an ADAPT VPA.

An XSA analysis is applied to the weakfish stock for direct comparison to the ADAPT results. Four age disaggregated fishery-independent indices are used in both the ADAPT and XSA analyses. In addition, several indices of juvenile abundance are employed in the XSA analysis (data provided by ASMFC Weakfish Stock Assessment Subcommittee). Indices are developed for the period from 1982-2001, while the fishery catch-at-age matrix and associated data are currently available only from 1982-2000. In addition, XSA evaluation runs were compared to an integrated catch-at-age analysis (ICA) of the weakfish stock that was explored during the 2001 assessment (Kahn, 2002a).

2.3.2 Fishery Catch-at-age

The fishery catch-at-age matrix reflects both commercial and recreational landings, but includes discards from only the recreational fishery. Catch-at-age data are supplied either individually by state, or by estimating catch-at-age from length-frequency data and applying regional length-weight and age-length relationships as appropriate (Kahn, 2002a). The resulting catch-at-age matrix includes the period from 1982-2000 and includes age classes 1-6+ (Table D.8). For MSVPA-X evaluation runs, the catch matrix is projected forward to include 2001 and 2002 based upon fishing mortality rates and population sizes calculated through 2000.

2.3.3 Fishery-Independent Surveys

Four fishery-independent surveys provide age-specific indices of weakfish abundance for use in tuning the ADAPT and XSA approaches. Only surveys encompassing the region between North Carolina and Delaware are used: the New Jersey coastal trawl survey, a Delaware Bay survey, the SEAMAP fall coastal survey in North Carolina waters, and the NMFS fall inshore survey (Kahn, 2002a). In addition, several juvenile indices based upon haul seine surveys in estuarine waters are included: the VIMS haul seine (age-1), the North Carolina DMF survey (ages-1 and -2), two surveys by Maryland DNR (both age-1), and a Delaware Bay survey age-1).

2.3.4 Age and Growth

Size and weight-at-age are estimated from year specific von Bertalanffy parameters developed by Vaughan (unpublished data) for the period from 1990-1999 based upon otolith data (Kahn 2002b, pers. comm., D. Vaughn, SEFSC). Due to uncertainties in the methods used for length and weight analyses, the average derived weights and lengths from the 1990-1999 period are used in the MSVPA-X base run (Table D.9).

2.2.5 Single-Species VPA

The XSA model is used as the single-species VPA approach for weakfish. A series of XSA evaluation runs were developed for the period from 1982-2000 for comparison to the ADAPT VPA and integrated catch-at-age (ICA) analysis used in the 2002 assessment document. The

catch matrix included ages 1-6+ and the same indices were used in the XSA as in the standard assessment models. A constant natural mortality rate of 0.25 was assumed for weakfish.

The XSA for weakfish was largely insensitive to shrinkage parameters, and varying the number of years or age classes used to estimate terminal F values had little effect. The qualitative trends are similar for the ICA, XSA, and ADAPT models with the exception of the last two years of the assessment (Figure D.12). The XSA tends to underestimate fishery mortality rates on older age classes through most of the time series compared to the other two models. However, in the last two years of the assessment, the ADAPT approach estimated very low fishery mortality rates for ages 3-5 compared to the other two approaches (Figure D.13). Concern was expressed in the 2002 assessment about severe retrospective bias in the ADAPT approach and significant underestimation of F in the terminal year (Kahn 2002a). The fishing mortality rate estimates in the last two years for the XSA are more similar to those estimated by the ICA model (Figure D.13).

Abundance estimates from the three approaches diverge from one another beginning in the mid-1990s. From 1997-2000, the ICA and XSA models estimate declining abundance of older age classes, while the ADAPT estimates significant increases in the abundance of older fish during this time period (Figure D.14). For younger age classes, the ICA and XSA both predict declines during 1994-1997, while the ADAPT predicts continued increases. The ICA model indicates increases in the abundance of young weakfish during 1998-2000, while the XSA model indicates continued decline (Figure D.14).

The divergent results of the three age-structured assessment models used here likely reflect problems with the catch-at-age matrix described in the 2002 assessment. Another problem is that only two fully recruited true age classes are in the current assessment.

2.4 BLUEFISH

2.4.1 Summary of Fishery and Assessment

Bluefish landings are primarily from recreational fisheries along the U.S. Atlantic coast and in estuaries between Maine and Florida. Commercial fishery operations in coastal waters also land bluefish in several gillnet and trawl fisheries; however, the commercial landings are consistently below those of the recreational fishery (Lee, 2003). The biomass of the bluefish stock declined during the period from 1982-1992 and continued at low levels through 1998. Amendment 1 to the FMP was adopted in 1998 in an effort to rebuild the stock by 2007 through gradual reductions in fishery mortality rate. The stock assessment model results used in the MSVPA-X indicate that fishing mortality rates in the terminal year (2002) are below target levels and there have been recent increases in stock abundance.

The biomass dynamics model (ASPIC) previously used to assess the bluefish stock utilized commercial and recreational landings data. The recreational CPUE and NEFSC inshore fall survey are used as tuning indices in this approach. The stock had not been assessed using an age-structured approach, primarily due to concerns at the time, about the validity of reliable ageing. Prior to the 2005 stock assessment, the most recent age-structured assessment included catch-at-

age through 1997 (NEFSC, 1997), and at that time age-length keys were available only from North Carolina. In 2005, a forwarding projecting model (ASAP) was used to assess the bluefish stock and also determined fishing mortality to be below target levels and population abundance has been increasing since 2000. Though the peer reviewers had concerns regarding the 2005 assessment, it was accepted for management purposes (NEFSC, 2005).

Due to the unavailability of catch-at-age information from a peer reviewed stock assessment during the model reference period (1982 – 2002), bluefish is included in the MSPVA-X application as a “biomass predator”. In this formulation, the predator population dynamics are not modeled. Model input requirements include a time series of total predator biomass, limited information on predator size structure, and feeding selectivity parameters.

2.4.2 Biomass Input

The time series of bluefish stock biomass from 1982-2002 is derived from the ASPIC Biomass Dynamic model used in the ASMFC stock assessment (Lee, 2003). The model uses recreational CPUE and the NEFSC inshore fall bottom trawl survey as tuning indices. Lee (2003) points out several areas of concern with this assessment model including: uncertainty as to the appropriateness of the NEFSC survey as an index of total biomass, assumptions of constant catchability in the fishery, and general concerns with the base assumptions of the simplified biomass dynamic model. The time series of total bluefish biomass is shown in Figure D.15.

2.4.3 Size Structure

An analysis of bluefish diet information based upon the Northeast Fisheries Science Center Food Habits database indicated significant breaks in bluefish diets in three size classes: 10-35 cm (ages 0-1), 35-55 cm (ages 2-3), and > 55 cm (ages 4+). These three size classes were used in the MSPVA-X model to account for ontogenetic changes in feeding selectivity and consumption parameters. The proportion of the total biomass in each age class was estimated based upon the average size distribution from the previous age-structured assessment (NEFSC, 1997). The proportion of biomass calculated for each size class was: Size 1 – 0.07; Size 2 – 0.21; Size 3 – 0.71.

2.5 ‘OTHER PREY’ COAST WIDE BIOMASS ESTIMATES

2.5.1 Benthic Invertebrates

The three primary benthic invertebrate taxa important in the diets of weakfish, bluefish, and striped bass include gammarid amphipods, isopods, and polychaetes. The benthic invertebrates, particularly gammarids, are most important in the diets of young striped bass in the Chesapeake Bay, with gammarids accounting for up to 80% of the diet during some seasons (Hartman and Brandt, 1995). Over the continental shelf, gammarids are also the primary benthic invertebrate consumed by weakfish and striped bass, typically accounting for 5-15% of the observed diet Northeast Fisheries Science Center Food Habits database. Bluefish tend to have low amounts of benthic invertebrates in their diets.

Regional density estimates for these benthic invertebrate taxa were developed from a systematic benthic sampling program of the U.S. Atlantic continental shelf described in Wigley and Theroux (1981) and Theroux and Wigley (1998). This study was a comprehensive quantitative sampling of the benthic invertebrate community conducted during the 1950s and 1960s. Sampling was conducted using quantitative grab samplers. Results in the referenced reports provide maps and taxa specific density estimates in areas consistent with the regional definitions used in the current analysis. Densities are provided as g m^{-2} , and these were converted into biomass by multiplying regional density values by area, calculated using GIS tools (Table D.10). These data are not seasonally or annually resolved; therefore, constant biomass values were used across seasons and years in the current MSVPA-X application. While these estimates of benthic invertebrate biomass are based upon data several decades old, there is no more recent broadscale estimate of benthic biomass available over the U.S. Atlantic continental shelf. The resulting total estimated biomass of benthic invertebrates is 3,357,000 mt.

The size structure of the benthic invertebrate taxa was inferred from general descriptions of the observed size ranges in these habitats. This prey type was assumed to range between 1-7 cm in body length with peak biomass occurring at 3 cm. The resulting biomass distribution input into the MSVPA-X application is shown in Figure D.16.

2.5.2 Macrozooplankton

Crangonid shrimps, mysids, and other large zooplankton are primary prey items for young age classes of each predator species. However, there is no systematic information available on densities or biomass of these along the mid-Atlantic coast. Monaco and Ulanowicz (1995) report total density of “mesozooplankton” in the Chesapeake, Delaware, and Narragansett Bays as part of a trophic food web model examining energy flow in these systems. The total carbon density (mg C m^{-2}) was converted to total biomass assuming that carbon accounts for 90% of dry weight and that dry weight is 10% of live weight. These estuarine densities were averaged to generate an estimated coast wide biomass density estimate of 13.3 mt per km^2 . Multiplying this value by the regional areas generated a total biomass estimate of 1,994,000 mt. An approximate length-frequency for macrozooplankton biomass based upon literature descriptions of these taxa is shown in Figure D.17.

2.5.3 Benthic Crustaceans

Benthic crustaceans including crabs and lobsters make up a small, but consistent, proportion of the diet of striped bass, bluefish, and weakfish. For striped bass, blue crabs have been observed to make up a significant proportion of the diet (typically 10-20%) in some seasons in estuarine habitats (Hartman and Brandt, 1995). Over the continental shelf, the Cancer crabs (rock and Jonah crabs) are observed at low levels (1-3%) in striped bass diets, and in the inshore Gulf of Maine, lobsters accounted for 20-40% of adult diets in localized studies (Nelson *et al.*, 2003). The proportion of benthic crustaceans is lower in weakfish and bluefish diets, typically ranging between 1-3%.

As important commercially exploited species, both blue crabs and lobsters are the subject of detailed assessment work along the U.S. Atlantic coast. For blue crabs, assessment documents

provide biomass estimates in 10mm size intervals for Chesapeake Bay, Delaware Bay, and North Carolina (Eggleston *et al.*, 2004; Kahn and Helser, 2005; Sharov *et al.*, 2002). The total annual biomass estimates derived from assessment data are shown in Table D.11. The average biomass of blue crabs across the time series is 85,961 mt.

Data on lobster abundance along the Atlantic coast of U.S. were obtained from the ASMFC American Lobster Stock Assessment Report (ASMFC, 2000). Absolute abundance was reported for recruits, post-recruits and total for the Gulf of Maine, Cape Cod and Long Island areas for the period of 1982-1997 (Tables D.12 and D.13). Size distribution of lobster recruits from the intertidal study in the Gulf of Maine (Cowan, 1999) was similar to the size frequency of lobsters in striped bass stomach reported by Nelson *et al.* (2003). An estimated mean weight of recruits was applied to the absolute abundance estimates to produce total biomass of recruits for each year (Table D.14).

For rock and Jonah crabs, there is no detailed assessment data from which to derive information on total biomass. However, the NEFSC bottom trawl survey samples and quantifies both species. Trawl survey estimates of seasonal (Fall and Spring) and regional catch rates (number per tow) were summarized in Stehlik *et al.* (1991). These catch rates were converted into biomass per km² (Table D.15) assuming a trawl swept-area of 0.0315 km² and a mean weight of 63g per individual as reported in Stehlik *et al.* (1991). Rock crab densities in the Chesapeake Bay were assumed to be equal to those in the mid-Atlantic coastal waters based upon the spatial distribution described in Stehlik *et al.* (1991). Regional biomass estimates based upon swept area were 2,220 mt during fall and 253 mt during spring. These are recognized to be underestimates of total biomass since the trawl does not catch crabs with 100% efficiency.

Estimates suggest that the biomass of available benthic crustaceans is dominated by blue crabs. Averaged across the time series, the total estimated biomass for these three taxa is 91,471 mt. Due to the dominance of the blue crab component, the size distribution is based upon those developed for blue crabs from assessment data. The peak biomass is in the adult size classes between 13-16 cm carapace width (Figure D.18). This size range is larger than the range of prey consumed by striped bass and other species. Therefore, the available biomass of benthic crustaceans will be in the lower portion of this size range, consistent with the findings of diet studies showing that these predators feed primarily upon juvenile crabs.

2.5.4 Squid and Butterfish

Butterfish were last assessed using a forward-projection model (NEFSC, 2004). Length-frequency data for the commercial fleet are provided therein. Fishery-independent length-frequencies are available from the NEFSC fall bottom trawl survey (pers. comm., William Overholtz, NEFSC).

Northern Short-finned squid (*Illex*) were assessed in 2003 (NEFSC, 2003). This assessment uses various methods, including a fishery-independent index based on the NEFSC fall bottom trawl series, a maturation-natural mortality model, and both yield-per-recruit and egg-per-recruit models. Data on length-frequency were provided using the NEFSC fall bottom trawl survey (pers. comm., Larry Jacobson, NEFSC).

Long fin squid (*Loligo*) data are available through a peer reviewed assessment (NEFSC, 2002). *Loligo* were assessed using both a length-lased VPA and an index based assessment. Fishery-independent and dependent length-frequencies are available.

2.5.5 Clupeids

Clupeids (other than Atlantic menhaden) are abundant in estuaries and coastal waters along the U.S. Atlantic coast, and may constitute an important prey for each of the predators included in the MSVPA-X model. Landings were accumulated as available for four species, including Atlantic herring, Atlantic thread herring, Spanish sardine, and scads. Additionally, the MSVPA-X Assessment Subcommittee recognized the shads (American shad, hickory shad and the river herrings) as a regionally important prey item, but was unable to develop a coast wide estimate of abundance for these species due to data limitations. A coast wide assessment for American shad is scheduled for completion in 2006.

2.5.5.1 Atlantic Herring

Monthly landings of Atlantic herring (mt) were obtained for 1982-2004 from the northeast commercial fishery database (CFDB) as used in a recent stock assessment for Atlantic herring (Overholtz *et al.*, 2003). Annual landings are summarized in Table D.16. Seasonal landings across years are summarized in Table D.17.

Length composition data representing Atlantic herring for 1982-2004 (n = 253,274) were also available from the recent stock assessment (pers. comm., Matthew Cieri, Maine DMR). These data are summarized in Table D.18.

2.5.5.2 Atlantic Thread Herring

The biology of and fishery for Atlantic thread herring along the North Carolina coast is reported in Smith (1994). Monthly landings of Atlantic thread herring in North Carolina were obtained from NMFS's menhaden sampling program (pers. comm., Joseph W. Smith, SEFSC). Additional monthly landings of Atlantic thread herring from the east coast of Florida were obtained from the NMFS website for commercial landings statistics (<http://www.st.nmfs.gov/st1/commercial/index.html>). Annual landings are summarized in Table D.16. Seasonal landings across years are summarized in Table D.17.

Length (n = 990) and age (n = 628) compositions were also available from the NMFS menhaden sampling program (pers. comm., Joseph W. Smith, SEFSC). These data, from fish collected between 1982 and 2002, are summarized in Table D.19.

2.5.5.3 Spanish Sardines and Scads

Monthly landings of Spanish sardines and scads were also obtained from the NMFS website for commercial landings statistics cited above. Annual landings are summarized in Table D.16. Seasonal landings across years are summarized in Table D.17.

2.5.5.4 Stock Abundance

The recent assessment of the Atlantic herring stock suggested an approximate $F = 0.05$ (age-1+ in 2002). Based on this result, and noting that the landings of Atlantic herring are several orders of magnitude larger than the aggregate of other species presented here, combined landings were divided by F to obtain an estimate of population biomass for these species in aggregate. These values are presented annually from 1982-2004 (Table D.16).

2.5.6 Anchovy

Bay anchovy, *Anchoa mitchilli*, is one of the most abundant fish species in mid-Atlantic estuaries and coastal waters and is a primary prey item during some seasons and age classes for each of the predators included in the MSVPA-X model. Relatively little information is available regarding biomass and population dynamics outside of estuarine waters. However, there has been intensive study of larval dynamics, life history, and seasonal patterns in biomass inside of Chesapeake Bay (Lou and Brant, 1993; Newberger and Houde, 1995; Rilling and Houde, 1999).

2.5.6.1 Estuary Biomass Estimates

Bay anchovy are a short-lived species in Chesapeake Bay, rarely are there more than three age classes in the population. During most of the year, bay anchovy biomass in the bay is relatively constant; however, during the late summer and fall following recruitment, anchovy biomass increases dramatically as age-0 fish undergo rapid growth (Newberger and Houde, 1995). Rilling and Houde (1999) estimated baywide biomass during June and July at approximately 23,000 mt. During peak densities during fall, they cite studies indicating biomass levels peaking at over 100,000 mt. Biomass levels of 23,000 mt are assumed typical of winter and spring. Biomass is assumed to increase to 100,000 mt summer (July – September) and then decline to 60,000 mt during the fall.

2.5.6.2 Coastal Biomass Estimates

The New Jersey Ocean Trawl Survey (NJ OTS) database was used to develop bay anchovy biomass estimates for nearshore coastal waters. The survey started in 1989 and samples nearshore waters (3 fathom – 15 fathom isobaths) from the entrance of New York Harbor south to Delaware Bay five times a year (January, April, June, August and October). There are 15 strata – 5 strata assigned to 3 different depth regimes (inshore – 3 to 5 fathoms, mid-shore – 5 to 10 fathoms, and offshore – 10 to 15 fathoms). Station allocation and location is random and stratified by strata size. The total weight (kg) of each species is measured and the length of all individuals, or a representative sample by weight for large catches, is measured to the nearest cm.

The average area swept per tow (km^2) was derived from the trawl mouth opening (wing spread x vertical opening) and the average distance covered per trawl. We then determined the average total area swept by season (**season 1** – 1 survey cruise and 30 stations, **season 2** – 2 survey cruises and 80 stations, **season 3** – 1 survey cruise and 40 stations, **season 4** – 1 survey cruise

and 40 stations) and determined the multiplying factor (area swept per season / total survey area) to develop estimates of absolute abundance and biomass. We developed a yearly, weighted (by stratum size) CPUE index (by number and biomass per tow) by season, and then multiplied that value by the number of tows within the season to determine the average total abundance or biomass caught for the season. By multiplying that value by the multiplying factor, we developed estimates of absolute abundance or biomass (mt) for that year and season. Using the mean biomass estimate for the time series (1989-2004), the total seasonal biomass estimate along the New Jersey coast was derived.

The seasonal biomass estimates and seasonal trends for bay anchovy off the New Jersey coast are different than those for Chesapeake Bay (Figure D.19). Anchovy biomass along the coast increases throughout the year and reaches its peak biomass in the fall as anchovies begin to move out of the estuaries and into the coastal waters.

2.5.6.4 Estuary Time Series Index

Data from the New Jersey Department of Environmental Protection (NJ DEP) Delaware River seine survey, Virginia Institute of Marine Science (VIMS) trawl survey, VIMS seine survey, Maryland Department of Natural Resources seine survey, Maryland DNR coastal bay seine survey and Delaware Department of Natural Resources and Environmental Control Delaware Bay juvenile trawl survey were used to develop a yearly *estuary* bay anchovy index. We first developed separate Chesapeake Bay and Delaware Bay indices using the appropriate surveys. We z-transformed (+ 2) the annual CPUE indices in order to normalize and standardize the data. The Chesapeake Bay indices are highly correlated and all surveys show a clear decline in anchovy abundance (Figure D.20); the Delaware Bay indices are not correlated and are much more variable and neither survey shows a clear trend in abundance (Figure D.21). To create one index for the Chesapeake Bay, we weighted the surveys according to length of time series, number of samples, and the spatial and temporal range of the survey – the surveys had the following weighting factors: VIMS seine – 0.3, VIMS trawl – 0.3, MD DNR seine – 0.3 and MD DNR coastal bay – 0.1. The same procedure was followed to develop the Delaware Bay index, with both surveys assigned a weighting factor of 0.5. In order to combine the two surveys into one grand estuary index that would be applied to other estuary waters along the Atlantic coast, we re-weighted the two surveys in reference to each other by their total area (km²) – Chesapeake index weighting, 0.788 and Delaware index, 0.212. Figure D.22 shows the combined Chesapeake Bay index, the combined Delaware Bay index and the combined *estuary* index.

2.5.6.5 Coastal Time Series Index

Data from the NJ OTS and the Southeast Area Monitoring and Assessment Program (SEAMAP) survey were used to develop the yearly *coastal* bay anchovy index. As with the estuary indices to normalize and standardize the surveys, we z-transformed (+3) the annual CPUE values. The surveys were not significantly correlated but both show a decrease in anchovy abundance over the course of the time series – NJ OTS 1989 – 2004, SEAMAP 1990 – 2004 (Figure D.23). In order to combine the two indices and develop one coast wide annual index, we weighted each z-transformed index. Weighting factors were estimated by comparing the survey area sampled, time series length, number of samples collected and the temporal range of the surveys. For this

case both the NJ OTS and the SEAMAP survey were assigned a weighting factor of 0.5. Those values were then added to derive the single annual *coastal* index value (Figure D.23).

2.5.6.6 Time series of Seasonal Density and Biomass Estimates

Estuaries: The seasonal estuary biomass estimates developed by Rilling and Houde (1999) were determined from data collected in 1993. Since we developed a single seasonal biomass estimate, we used 1993 as the ‘reference year’ and scaled the annual (1982 – 2002) estuary indices to the 1993 index to determine the annual seasonal biomass estimates. We first determined the annual seasonal densities (biomass km⁻²) for each of the estuaries along the coast – Buzzards Bay, Long Island Sound, Hudson River Estuary, Delaware Bay, Chesapeake Bay, Neuse River and Pamlico Sound (GIS tools were used to determine estuary and coastal water area – km²). We assumed the density inside Chesapeake Bay is similar to that in other estuaries, but applied the appropriate scaled index value to the appropriate estuary to develop the season densities (ex. formula: {season biomass * scaled index value} / area). The calculated seasonal densities were then multiplied by the respective estuaries total area (km²) to determine the annual seasonal biomass estimates for each estuary. We then summed all of the individual estuary estimates to determine the total estuary bay anchovy biomass.

Coast: A similar procedure was followed with the coastal estimates. For consistency with the estuary estimates, we scaled the annual coastal estimates to the 1993 reference year to determine the annual seasonal biomass estimates (Note: from 1982 through 1988, coastal biomass estimates are constant and are equivalent to the 1993 reference year because the coastal surveys used in this analysis began in 1989). We determined the annual seasonal densities (biomass km⁻²) for the New Jersey coast and the remaining coastal waters (out to 10 nautical miles from shore) and assumed the density along the Jersey coast was similar to that along other parts of the coast and applied the appropriate scaled index value to develop the seasonal densities. As with the estuarine estimates, the calculated densities were multiplied by the corresponding coastal total area and then all of the coastal areas were summed to get the total coastal bay anchovy biomass.

The total estuary and coastal estimates were then summed to develop the overall annual seasonal bay anchovy biomass (Table D.20).

The length-frequency of bay anchovy is summarized in Newberger and Houde (1995) and length-frequency data from the New Jersey Ocean Trawl Survey show a similar size range.

2.6 DIET SELECTIVITY INDICES

The selectivity model used in the MSVPA-X relies upon a rank index for prey type preference. These indices are derived from summaries of available diet composition data when they are available. For the predators considered here, there are multiple diet studies published in the literature; however, these are generally smaller scale studies focusing on particular places, seasons, and time periods. The most spatially and temporally comprehensive data set for all three species is the Northeast Fisheries Science Center Food Habits database. However, this survey is limited to the coastal (i.e., non-estuarine) waters, is only available during spring and fall, and generally does not have large sample sizes for older fish. For each species, there are additional

regional studies that provide diet information for estuarine waters and/or other times of the year. A compilation of regional studies and NEFSC Food Habits database was used to develop overall rank indices of type preference for each predator species and age class.

The strategy used to develop type indices for each predator is outlined as follows:

- 1) For each region, summarize available data to develop an average diet for each season and age class.
- 2) Calculate the seasonal biomass of each prey type in the region based upon the estimated biomass and spatial distribution of each prey type (used in the spatial overlap analyses).
- 3) Calculate a quantitative electivity index as the ratio between the proportion of the prey in the diet versus the proportion of the prey biomass, and normalize so that these electivity values sum to one. This is equivalent to calculating Chesson's electivity index.
- 4) For each predator age and prey type, calculate the average of this quantitative index weighting by the proportion of the predator biomass in each region. Thus, the average selectivity will therefore reflect data from the region(s) containing the majority of each predator's biomass.
- 5) Rank the resulting overall values, and use these as the rank type-preference index in the model. The rank indices reduce the effects of poor estimation of biomasses in each region that may result in biases in the quantitative indices.

As an example of the data used to derive these indices, we present the diet information for striped bass from Chesapeake Bay. There are a number of primary sources of diet information in the published literature for striped bass (Table D.21) encompassing all of the regions, age classes, and seasons used in the current application. For early age classes of striped bass, the most comprehensive available data set is from Hartman and Brandt (1995). This study includes fish sampled across most of the Chesapeake Bay including the main-stem and tributaries. Samples were collected during the early 1990s and across most months. The seasonal diet compositions used for age classes 0, 1-2, and 3-5 based upon this study are shown in Figure D.24. Generally, age-0 fish fed primarily upon benthic invertebrates during the early part of the year and anchovies and macrozooplankton during the later part of the year. Age 1-2 and 3-5 fish were more piscivorous, and their diets were dominated by menhaden except for season 2 when sciaenids were more important (Figure D.24a).

The samples collected in Hartman and Brandt (1995) did not include older age classes. Therefore, diet information for older fish was taken from Walter and Austin (2003) using samples collected during 2000-2001 across most of the Chesapeake Bay and most seasons. The seasonal patterns for both age groups are similar with medium forage fish (made up primarily of *Alosa* spp.) comprising the majority of the large fish diets during the early part of the year and menhaden and sciaenids during the later part of the year (Figure D.25). Benthic crustaceans (primarily blue crabs) were also an important component of the diet for age 6-7 fish during the spring (Figure D.25a).

The proportion of total biomass in the Chesapeake Bay by prey type is shown in Figure D.26. These seasonal values are derived from information on the seasonal spatial distribution of each taxon and the estimated total biomass of each. It is important to note that the “medium forage fish” category does not well represent the biomass of that prey type in the Chesapeake Bay since biomass estimates for *Alosa* spp. and other small fish were not available. Based upon the available data, anchovies represent the majority of the prey biomass in the Chesapeake Bay in all seasons.

Quantitative values for Chesson’s electivity index were calculated as the ratio between the proportion of each prey in the diet and the proportion of total prey biomass in the region. The seasonal values for each striped bass age class and prey type are shown in Table D.22. A similar analysis was conducted for all other regions using the data sources listed in Table D.21. These quantitative scores were then averaged across regions and seasons weighed by the biomass of each age class of striped bass. These averages were ranked to provide the indices input into the MSVPA-X application shown in Table D.23.

In contrast to striped bass, there are very few references for regional and seasonal diet composition for weakfish. Hartman and Brandt (1995) is the primary data source for the Chesapeake Bay, while diet information for the remainder of the study is limited to the Northeast Fisheries Science Center Food Habits database (Table D.24). Based upon this somewhat incomplete picture of weakfish diets, the resulting type preference ranks are shown in Table D.25.

The primary data source for bluefish diets is also Hartman and Brandt (1995) for the Chesapeake Bay and the NEFSC food habits database for larger fish in the remaining regions (Table D.26). The NEFSC food habits data are also described in Buckel *et al.* (1999). There are a number of additional studies (Buckel *et al.*, 1999, Juanes *et al.*, 2001, Buckel and Conover, 1992), primarily in the New England region, examining the diets of age-0 bluefish and these were also incorporated into the current analysis. The resulting type preference ranks are shown in Table D.27.

2.7 SPATIAL OVERLAP INDICES

2.7.1 Model Spatial Domain

While the MSVPA-X model is not fully spatially explicit, it is necessary to define a spatial domain and strata at regional scales to evaluate seasonal spatial overlap between predators and prey. The spatial resolution of these strata is primarily limited by available data on the spatial distribution of the species included in the model. Ideally, a broad scale scientific survey would capture all predator and prey species at a relatively high spatial resolution. However, this is rarely the case, and in particular spatial data on invertebrate and small fish prey are typically limited.

The spatial domain for the current model application was developed based upon the known spatial distribution of the four primary species. Five regional strata were defined (Figure D.27,

Table D.28) ranging from North Carolina to the Gulf of Maine. The offshore extent of the model was defined as 20 nautical miles from shore for coastal strata. Georges Bank (defined by the 200m isobath) was included in the Gulf of Maine (GM) stratum. These strata areas are used to expand the densities of invertebrate and other prey to total biomass. In the case of data from the NMFS bottom trawl survey, stations were assigned to strata based upon their reported latitude and longitude locations.

Commercial and recreational landings data were used to evaluate the spatial distribution of several species. While landings data are subject to several biases, there is no comprehensive regional survey providing spatial distribution data for the larger predators. The NMFS bottom trawl survey provides some data; however, it is inefficient at catching these larger more pelagic predators, does not sample nearshore waters, and does not include sampling in Chesapeake Bay. The bottom trawl survey is also limited to primarily the fall and spring seasons. Landings data therefore provide the best available measure of the relative spatial distribution of the predators included in this model.

Landings data were matched to the regional strata based upon the reported state (Table D.28). Landings data were downloaded for the period from 1982-2002 (where available) from the NMFS website (<http://www.st.nmfs.gov/st1/commercial/index.html>) by state, month, and area (inland versus offshore). For the recreational (MRFSS) data, the two-month “waves” were divided evenly into monthly landings so as to define the seasonal totals. For Virginia and Maryland, nearly all commercial and recreational landings are from the Chesapeake Bay region. The total landings were thus calculated for each season and region

The spatial distribution of each taxon was evaluated on a seasonal basis using landings, survey, or regional density data as appropriate. These relative spatial distributions were then used to calculate the seasonal spatial overlap (using Schoener’s index) between each predator age class and each prey species.

2.7.2 Striped Bass

The seasonal spatial distribution of striped bass based on landings data is shown in Figure D.28. During the winter months (season 1), striped bass is concentrated in the southern portion of the range, particularly in North Carolina and Chesapeake Bay. During spring, the landings increased in the northern portion of the area, and this trend continued through season 3 where the majority of landings are concentrated in the New England and Gulf of Maine strata. During the fall months, the landings were highest in the mid-Atlantic and Chesapeake Bay regions as the stock moves south (Figure D.28). These spatial patterns in the total biomass were converted into age-specific spatial distribution based upon the observed age-structure of the catch within each region (Figure D.29).

2.7.3 Weakfish

Weakfish seasonal distribution patterns were similar to those observed for striped bass; however, weakfish did not occur as far north during the spring and summer (Figure D.30). In the winter, weakfish landings primarily occurred in the North Carolina region. The weakfish stock

progressed north during the spring and summer with landings concentrated in the mid-Atlantic region, and occurring in the Gulf of Maine area only during the summer months. During fall, the stock again moved south and was concentrated in the mid-Atlantic and Chesapeake Bay areas. The regional age structure of the catch is shown in Figure D.31 and was used to calculate age-specific seasonal spatial distribution of the stock.

2.7.4 Bluefish

The spatial distribution of the bluefish stock showed a similar seasonal progression to that of the other predator species (Figure D.32). During the winter, the landings were concentrated in the North Carolina and mid-Atlantic regions. Landings increased in the northern regions during spring. In summer and fall, the landings were highest in the southern New England stratum. Unlike weakfish and striped bass, there are no available data on the regional age structure from commercial landings; therefore, the spatial distribution of different size classes used were derived from the NMFS bottom trawl survey. The spring bottom trawl survey was used as the proxy for the winter and spring seasons while the fall survey was used for the summer and fall. The relative mean catch per tow in each region for each season (Figure D.33) was used to calculate the seasonal spatial distribution of each size class.

2.7.5 Menhaden

The seasonal spatial distribution of Atlantic menhaden was derived from the time series of purse seine landings. The relative distribution of landings of ages 0-2 menhaden were used since this size range is the primary component of predator diets. Menhaden landings occurred exclusively in the North Carolina region during winter months. During spring, landings were concentrated in the mid-Atlantic region and southern New England. In the summer, landings are concentrated in the Chesapeake Bay and then again in the North Carolina and Chesapeake Bay in the fall (Figure D.34).

2.7.6 Other Fish Prey

For medium forage fish (primarily butterfish and squid) and herrings (primarily Atlantic herring), seasonal spatial distribution was derived from the mean catch per tow in each region from NMFS bottom trawl survey data. Since the survey does not sample inside the Chesapeake Bay, stations from offshore waters of Virginia and Maryland were used as a proxy. The spring survey was used as a proxy for seasons 1 and 2, and the fall survey for seasons 3 and 4. The relative distribution of medium forage species was highest in the North Carolina and Gulf of Maine regions during the colder seasons (Seasons 1 and 2), and highest in the Gulf of Maine for summer and fall (Figure D.35a). The herrings were distributed throughout the region during the colder months, but were highest in the Gulf of Maine. In the warmer months, nearly all of the clupeid biomass was in the Gulf of Maine region (Figure D.35b).

The spatial distribution of the sciaenids (croaker and spot) was derived from commercial landings data, similar to the approach used for the predator species. Sciaenid landings were concentrated in the North Carolina region during the winter, then further north in the Chesapeake

Bay region during spring and summer, and again in North Carolina during the fall (Figure D.35c).

2.7.7 Anchovy and Invertebrate Prey

For the remaining other prey there was no seasonal data on spatial distribution available. Therefore, the regional spatial distributions are constant across seasons. For the benthic invertebrates, crustaceans, and macrozooplankton the relative spatial distribution is based upon the regional densities used to develop biomass estimates (see Section 2.5, Figure D.36). For anchovy, there is no coast wide measure of relative abundance. Therefore, arbitrary values were used centering the majority of the biomass in the North Carolina and Chesapeake Bay regions (Figure D.36).

2.7.8 Spatial Overlap Indices

The seasonal and age-specific relative distribution of biomasses was used to calculate spatial overlap values for each predator age class and prey type. These values are input into the MSVPA-X model as a component of the feeding selectivity equations (Tables D.29-D.31).

CHAPTER 3: MODEL PERFORMANCE AND SENSITIVITY ANALYSES

3.0 SUMMARY

The information below summarizes the base run configuration of the MSVPA-X that was used to evaluate model performance and sensitivity for the ‘retrospective’ MSVPA-X (See Sections 3.1 and 3.2). Section 3.3 reviews the set-up of the MSVPA-X forecast module. The results of the base run for the retrospective MSVPA-X are presented in Section 3.4. The sensitivity of the MSVPA-X to changes in input is presented in this Appendix (D1). Several analyses were conducted to evaluate the sensitivity of the MSVPA-X to changes in input parameters. Specifically, sensitivity of the model to changes in M1, prey type selectivity, prey size selectivity, predator weight-at-age, gastric evacuation rate parameters, predator and prey spatial overlap, and the addition and deletion of ‘other prey’ items are presented. An examination into the retrospective bias of the model in terminal year estimates is presented. A test of the forecast model is also presented that investigates the ability of MSVPA-X to reproduce past observations.

3.1 SINGLE-SPECIES CONFIGURATIONS

The following table details the MSVPA-X input data for each species (i.e., Atlantic menhaden, striped bass, weakfish, and bluefish) for the model’s base run configuration. The input data can also be reviewed in the MSVPA-X executable by opening the project file “BaseRun_07Sept_05.prj” and then opening “Open Species” listed in the options under File. Note that the options for bluefish are limited to feeding (consumption and prey size-selectivity parameters, as well as, the proportion of biomass in each size class) and biomass (time series of biomass estimates from the single-species assessment), as it is currently modeled as a “biomass predator”. The data input for explicitly modeled species includes catch-at-age, weight-at-age, size-at-age, maturity, and options regarding the single-species virtual population analysis. Feeding parameters (consumption and prey size-selectivity) for explicitly modeled species are entered under the MSVPA configuration (Section 3.2).

	Menhaden	Striped Bass	Weakfish	Bluefish
Catch-at-age	Stock Ass.	Stock Ass.	Stock Ass.	NA**
Weight-at-age	5 yr avg.	Constant	Constant	NA
Size-at-age	5 yr avg.	Constant	Constant	NA
Maturity schedule				
Age-0	0.00	0.00	0.00	
Age-1	0.00	0.00	0.90	
Age-2	0.118	0.00	1.00	
Age-3	0.864	0.00	1.00	
Age-4	1.00	0.04	1.00	
Age-5	1.00	0.13	1.00	
Age-6*	1.00	0.45	1.00	
Age-7	NA	0.89	NA	
Age-8	NA	0.94	NA	
Age-9 – 13+	NA	1.00	NA	

Single-species VPA Configuration	XSA	XSA	XSA
Apply shrinkage to the mean	Yes	Yes	Yes
CV for shrinkage mean	0.50	0.70	0.70
Number of years for shrinkage mean	4	3	3
Number of ages for shrinkage mean	3	3	2
Down weight early years	Yes	Yes	Yes
Weighting method	Tricubic	Tricubic	Tricubic
Earliest year for weighting	1982	1982	1982
M1	0.40	0.15	0.25
M2	0.00	0.00	0.00
Age-specific Natural Mortality Rates	No	No	No

* indicates the plus group for menhaden and weakfish (age-6).

** data for bluefish biomass time series is from the stock assessment (Lee, 2003); for details on bluefish feeding parameter data, see Table D.32.

3.2 MSVPA-X CONFIGURATION

This section details the steps and information used to configure the MSVPA-X for the base run. The MSVPA-X configuration process allows the model user to define the predator species (“Full MSVPA” or “Biomass Predator”) and prey species (“Full MSVPA”), the time frame and seasonality, add “Other Prey” species, prey type and preference of predators, predator-prey spatial overlap, predator consumption rates, predator seasonal gut fullness, and the type of single-species VPA used for each species. The following subsections provide the examples of the information used in the base run MSVPA configuration. Full details of the input data can be reviewed in the MSVPA-X executable by opening the project file “BaseRun_07Sept_05.prj” and then opening “Open MSVPA” listed in the options under File and navigating through the set-up options.

3.2.1 New MSVPA Configuration

Full MSVPA Species	Striped bass, weakfish
Prey only MSVPA Species	Menhaden
Biomass Predator	Bluefish

3.2.2 Enter time frame for MSVPA

Years	1982-2002
Number of Seasons	4
Season 1 Length (days)	92
Season 2 Length (days)	91
Season 3 Length (days)	91

Season 4 Length (days)	91
Seasonal Spatial Overlap	Yes
Model Predator Growth	No
Annual Temperature Variation	Yes (Table D.33)

3.2.3 Enter Other Prey Data

See Chapter 2 for full descriptions on methods and data used for each “other prey” species or group (anchovy, benthic crustaceans, benthic invertebrates, clupeids, macrozooplankton, medium forage fish, and sciaenids). The minimum and maximum size and parameters for each “Other Prey” item are listed in Table D.34. Biomass estimates for each “other prey” species by year and season are entered in this field.

3.2.4 Enter Prey Preferences

Prey preferences for each predator, by age, are entered in this field using the quantitative ranking methodology covered in Section 2.6. Predators cannot eat one another nor is there cannibalism, so, for each predator, the other predators are given a preference of 0 and the preferred prey item gets a ranking of 1. Ties in preference are entered as an average of the tied rank positions (e.g., if sciaenids and menhaden were tied for third in prey type preference, they would each receive a ranking of 3.5 which is the average of the third and fourth positions occupied in the matrix). Table D.35 contains the quantitative prey preference ranks for weakfish by age.

3.2.5 Enter Spatial Overlap Data

This field allows the user to define the seasonal spatial overlap between predators and prey. Again, since predators cannot eat one another and there is no cannibalism, each predator is given a rank of 0. See Section 2.7 for further details on the methods used to develop the quantitative spatial overlap indices. Table D.36 contains the quantitative spatial overlap rankings during season 1 for weakfish by age.

3.2.6 Enter Size Preference and Consumption Parameters

The parameters for prey size preference and consumption of each predator are entered in this field (Table D.37). For striped bass, parameters are entered for three age ranges (0-4, 5-9, and 10-13+), but for weakfish and bluefish age aggregated parameters are used. If higher resolution data were available then it would be possible to have age-specific values for each predator.

3.2.7 Enter Seasonal Mean Gut Fullness

In this field, mean gut fullness is entered for each predator by age or size class.

3.2.8 Select SSVPA for each species

For this configuration, the type of VPA used for each species (menhaden, striped bass and weakfish) was the XSA.

3.3 FORECAST MODULE

This section reviews the base configuration for the forecast module of the MSVPA-X. To run the forecast module, the 'retrospective' MSVPA-X configuration on which the forecast will be based must be selected. Then the user can select the year to start the projection and number of years to run the forecast module. Additional required inputs include von Bertalanffy parameters, length and weight relationships, and stock-recruitment relationships for each of the explicitly modeled species. Options for implementing the forecast module include: selecting fishery removal methods (catch versus fishing mortality), variable fishing mortality, other predator biomass, other prey biomass, and recruitment success. Each scenario can be saved. The MSVPA-X Assessment Subcommittee cautions against projections of greater than five years, as long-term projections are constrained to the stock-recruitment relationship of short-lived prey species.

3.3.1 Configure a Forecast Model

This entry screen allows the user to enter a name for the forecast and select an MSVPA configuration, the initial year of forecast, the number of years forecasted, and whether or not to model predator growth based on prey availability.

3.3.2 Enter von Bertalanffy Parameters

Parameters for the von Bertalanffy growth curve and the length-weight relationship for each explicitly modeled species are entered in this screen.

3.3.3 Stock-Recruit Parameters

Spawning stock biomass and recruit abundance data are entered for each explicitly modeled species for each year of the 'retrospective' MSVPA-X analysis. The user can select among the Ricker, Beverton-Holt, random from quartiles, and the Shepherd flexible methods to determine the stock-recruitment relationship for each species in the forecast.

3.3.4 Configure Forecast Scenarios

This is the final input screen before executing the forecast run. The user selects the method for modeling fishery removals, either catch limits in numbers or fishing mortality rate. The user can also opt to enter variable fishing mortality rates, other predator biomass, other prey biomass, and recruitment success.

3.4 BASE RUN RESULTS

3.4.1 Population sizes

The results of the MSPA-X Base run for explicitly modeled predators are given in Figures D.37 (total biomass) and D.38 (SSB). Biomass by size class for bluefish, the biomass input predator, is given in Figure D.40. Total biomass and SSB of striped bass increases over the time series.

Weakfish experience fluctuations in total biomass, but a general increasing trend in SSB is noted. It is notable that weakfish results from this iteration of the MSVPA-X differ from the most recent single-species assessment (See Chapter 2). Bluefish population biomass exhibits high abundance early in the time series (1982 – 1988), declines throughout much of the 1990s, followed by an increase in stock size in the last 3 – 4 years.

The only explicitly modeled prey species in this iteration is menhaden. Abundance and biomass trends are shown in Figures D.40 and D.41. Total abundance and abundance at maturity (age-2+) decline, although overall SSB has remained stable yet somewhat variable (Figure D.41). This can be explained in part by an increase in weight-at-age for menhaden (ASMFC, 2004a).

Menhaden total biomass is expressed in relation to other important prey items in Figure D.42. While menhaden and anchovy biomass decline, biomass estimates of other prey species are either stable (medium forage fish and sciaenids) or dramatically increasing (clupeids). The dramatic increase in clupeid biomass is in part due to the increase of Atlantic herring. Estimated current stock size for this stock is given elsewhere; but is thought to be approximately 1.8×10^6 mt SSB (Overholtz *et al.*, 2003). The increase in this stock has implications for both consumption by prey type and location (discussed below). It should be recognized that with the exception of menhaden, prey items in this iteration of the MSVPA are included as biomass inputs and are not explicitly modeled.

3.4.2 Diet composition

Average predicted diet compositions, across the available time series and seasons, are given for striped bass, weakfish, and bluefish (Figures D.43-D.45 respectively) by age (or size). In general, all predators are predicted to feed mainly on macrozooplankton and benthic invertebrates at younger ages or size classes. The diet composition for intermediate ages shifts to dominance by medium forage fish and anchovies. At older age classes, clupeids and menhaden dominate as many predators become more piscivorous.

One exception to the overall trend above is the prevalence of benthic crustaceans in the diet of striped bass at intermediate ages (ages 5-8). Nelson *et al.* (2003) suggest that as striped bass age, they tend to move farther north during the summer feeding period. Given this change in behavior and the lack of smaller menhaden in the prey field in this area, it is not unreasonable that striped bass in northern areas are predicted to feed more on benthic food sources than on menhaden and clupeids. At the oldest age classes (9-13+), however, type preferences apparently overcome availability, as clupeids tend to dominate the diet for the oldest striped bass. A similar result is seen in bluefish, but is lacking for weakfish; an expected result given that weakfish do not migrate as far north as the other predators.

3.4.3 Consumption and prey availabilities

Estimates of modeled consumption expressed as total biomass, for each important prey item by year are given in Figures D.46-D.48 for striped bass, weakfish, and bluefish (respectively). Striped bass increased consumption of all prey items during the time series, an expected result given their increasing abundance. Recent results suggest a decrease in benthic invertebrate

consumption, which is attributed to expansion of the striped bass population to older ages (Figure D.46; comments in section 3.4.1 above). Recent increases in consumption of both clupeids and menhaden may be the result of the expanding in age structure seen in striped bass.

Weakfish consumption exhibits no overall trend. Consumption of menhaden, benthic invertebrates, and anchovies is highly variable, but may show signs of recent increases in consumption by this stock.

Estimated consumption of fish prey by bluefish increases over time, particularly for the clupeids. While menhaden consumption is well below historical levels, clupeid consumption is at a historic high. The MSVPA-X Assessment Subcommittee suggests that this consumption rate may be the product of strong overlap between bluefish and clupeids in Northern areas and the recent increase in clupeid availability, and therefore cautions that clupeid consumption may be overestimated.

For explicitly modeled species, food availability can be tied to both natural mortality and growth rates in future iterations of the MSVPA-X; however, such is not possible at this time without additional data on the relationship between food availability and survivability of the explicitly modeled predator species. Overall, the prey available to striped bass has remained fairly constant across the temporal framework for the MSVPA-X (Figure D.49). The relative food availability for weakfish declines in relation to the decline in availability of their major prey, menhaden (Figure D.50).

3.4.4 Menhaden Predation mortality (M2)

Menhaden exhibit significant changes in predation mortality by age (Figure D.51-D.54). Age-0 menhaden M2 fluctuated, but it generally increases over time as the weakfish population increases. Likewise, M2 on age-1, 2, and 3 menhaden increases as predation by both striped bass and bluefish increases, as a result of both changes in the size- and age-structure of these predators and potential overlap with menhaden in recent years.

Overall, these results suggest that predation mortality increases as predator stocks rebound. This increase is not limited to younger age classes, as it extends to older menhaden than previously assumed. However, the scale of the graphs presented cannot be ignored. It should be recognized that size-at-age drives these interactions. For example, declining predator growth and an increase in prey size-at-age will dramatically affect the outcomes of this iteration. Overall, the M2 by included predators are mostly affecting age-0 to age-2 menhaden. For menhaden above age-2, M2 appears inconsequential.

CHAPTER 4: MODEL UTILITY FOR MANAGEMENT PURPOSES

Within the past few years many stakeholder groups, government officials, and scientists have called for an ecosystem approach to fisheries management on both the local and federal level. However, while managers have traditionally relied on analytical methods to help them make informed choices, few analytical tools are available to evaluate decisions at the ecosystem level. This MSVPA-X model was conceived to provide support to decision makers to enable them to make informed decisions in a multispecies context. This analysis is similar to most models used in fishery science in that it relies on past performance. The committee suggests that this iteration of the MSVPA-X has management utility while providing important caveats in interpretation.

The committee notes that this model is not designed for setting reference points or harvest limits for single-species. Additionally, the model intentionally encompasses a broad geographic range and therefore examination of local abundance or depletion is not possible. The MSVPA-X was conceived, in part, to provide accessory information and not to replace the single-species assessments already in place. Moreover, this formulation employs the XSA method for ease of calculation. Although every effort is made to develop configurations that reflect the single-species assessment results, results for individual species in the MSVPA-X framework may not correspond exactly to the outputs from the single-species assessments as peer reviewed.

The MSVPA-X, in principle, may examine prey availability and then tie that availability to both growth rates and its effects on the predator species by age class. However, until survivability of any given year-class, or predator stock, is examined relative to prey availability, such calculations are not possible. Further, the effects of prey availability on growth and recruitment of the predator species have been left out of the base run, so that this review examines the interactions among predators and prey without the confounding effect of predator growth.

As mentioned earlier, the MSVPA-X includes a forecast module that provides modelers the unique ability to explore the potential effects of various recruitment success, fishing patterns or pressure, and the availability of “other prey” items on the changes in stock size and dynamics of explicitly modeled species. Example projection scenarios provided here utilize “status quo” fishing mortality rates for fully modeled predator and prey stocks. Fishing mortality, stock size of “other” prey items, and their availability to the predators are all fixed in time and space by the user and are not part of the dynamic model structure. Any projections are subjected to the limitations of the recruited prey species. While longer-term projections are desirable to examine management objectives for longer-lived predator stocks, this iteration relies on the modeled recruitment. Therefore, it is subject to the limitations of our ability to predict recruitment for the explicit prey and predator species, and our abilities in this area are admittedly poor for various reasons. Due to their short life spans and environmentally driven recruitment, forage species may depart radically from their predicted population sizes making long-term predictions highly variable. Moreover, such departures could cascade to affect prey population sizes by season and, consequently affect growth and recruitment of the predator stocks. This, in turn, may affect prey availability for all predator species.

It is made clear that while the “other prey” items are included in this iteration of the MSVPA-X, and represent the best estimates available, they are not explicitly modeled and are instead primarily inputs into this analysis. Further, they are grouped by “type” to reflect guild functions within the prey field and in their respective ecosystems. Consequently, model outputs defining consumption of these should be used with caution. Resulting population sizes of these “other prey” items in this analysis should not be used for management. Decision makers are pointed to the single-species assessments, where available, for the “other prey” items instead.

With that said, the model has the potential to improve assessments in single-species assessments by suggesting the natural mortality rate at age (or by year, as appropriate) for explicitly modeled prey species. This has already been accomplished for menhaden in the 2003 assessment (ASMFC, 2004a). An earlier iteration of MSVPA-X produced the estimates of menhaden natural mortality at age; however, menhaden population size was estimated using a separate single-species assessment model and overall natural mortality was specified within that single-species assessment.

Additionally, decision makers can be shown potential impacts of fishing and predation mortality by age class for explicitly modeled prey. Such an analysis may suggest optimum harvest strategies for both predators and prey when fisheries for both exist and are managed under the same body. Further analyses may allow for the management of prey using total mortality, rather than fishing mortality. The model may also provide insight on multiple species target biomass based on trade offs among predators and prey. The model may provide additional guidance for rebuilding predator stocks by allowing the investigation of the interactions of specific predator biomass targets and the availability of prey species for other modeled predator stocks should that target be realized.

The seasonal resolution in this model may provide an insight as to when an explicitly modeled prey stock could be important for a given predator. MSVPA may pinpoint specific seasons when particular prey items are important for particular predators and how different predators may affect each other. However, seasonal importance is primarily defined by the modeler by specifying spatial overlap and type preference. Indirect interactions between predators can be examined primarily in the forecasting module that is also derived seasonally.

MSVPA-X may help decision makers determine appropriate size and bag limits for a given predator species. The model indicates that changing a predator’s age structure may affect prey species under certain régimes. Changes in bag limits and selectivities for a predator species may therefore affect prey availability, consumption, and prey availability for other species. Such analyses will require further modeling outside of the MSVPA-X, but are not inconceivable.

Competition and cannibalism are not explicitly modeled within this iteration of the MSVPA-X; these components can be incorporated explicitly at a later date. Nonetheless, competition is implied within the MSVPA. Changes in a predator’s total consumption can affect availability of that prey to other predators. Such changes may become more pronounced if competition and cannibalism are introduced. While growth of the predator stocks based on prey availability was not investigated in the presented analysis, the model does provide an option to perform this function.

The projection portion of the MSVPA-X provides ample opportunities to explore many different scenarios, which may be useful in both the moderate and long-term. While the committee cautions against the use of long-term projections using this iteration, even short-term projections have the capability to enhance management decisions. Changes in predator stock sizes and age structure, changes in prey recruitment success or failure, changes in management for both predators and prey, and changes in spatial and temporal overlap among modeled stocks can now be examined using an analytical approach. Moreover, such changes can be examined in light of both predators and prey.

Based on thorough review and testing of the MSVPA –X model, the committee suggests that this formulation is capable of answering management questions about predator-prey interactions among explicitly modeled species. With clear understanding the MSVPA-X’s abilities and limitations described above, the MSVPA-X approach has the potential to provide much accessory information for fisheries managers.

CHAPTER 5: ASMFC RESEARCH RECOMMENDATIONS

5.0 SINGLE-SPECIES ASSESSMENTS

As the MSVPA assessment depends heavily on the quality of data from single-species stock assessments, completion of existing research recommendations for single-species assessments will improve the utility of the MSVPA-X (See Appendix D2. Single-species Research Recommendations). In future MSVPA-X assessments, the most recently updated and peer reviewed single-species stock assessments will be used in the MSVPA-X.

5.1 MULTISPECIES RECOMMENDATIONS FROM ASMFC INTERNAL PEER REVIEW

5.1.1 Model Formulation

Short-term

These short-term research recommendations from the ASMFC Internal Review have been completed:

- Document how parameters are estimated within model with a flow chart to present the order of the estimation process.
- Add option to permit partitioning of biomass (vary size-structure of biomass predators) predators in forecast projections.
- Add option to input a recruitment vector in the forecast projection model.
- Add option to input catch as opposed to F into forecast projection model to simulate quota management approaches.

Long-term

The following long-term research recommendations from the MSVPA-X Internal Peer Review still remain:

- Add uncertainty to model forecast and incorporate elements of Monte Carlo simulations on recruitment curves.
- Alter biomass predator bin sizes for more flexible way to vary for projection model.
- Add ICA and production model options to retrospective.
- Develop a similar application to the “amoeba” program that allows the user to easily vary changes in model parameters.

5.1.2 Data

Short-term research recommendations

Updated diet data were obtained from several of the sources cited in the MSVPA (pers. comm., Jeff Buckel, North Carolina State University; pers. comm., Anthony Overton, East Carolina University; pers. comm., Wilson Laney U.S. Fish and Wildlife Service; pers. comm., Chris

Bonzek Virginia Institute of Marine Science; pers. comm., Joe Smith, SEFSC); however, some of the data could be obtained or had not been updated from earlier compilation efforts.

New ‘Other Prey’ species were added to the model. The full suite of ‘Other Prey’ includes:

1. Sciaenids (spot, croaker)
2. Small Forage Fish (anchovy, silversides, and sand lance)
3. Medium Forage Fish (butterfish, squid, mullets)
4. Clupeids (Atlantic herring, thread herring, and others)
5. Benthic invertebrates (worms)
6. Benthic crustaceans (lobsters, blue crabs, jonah crabs, calico crabs)
7. Macrozooplankton (shrimps, mysids, amphipods)

A reasonable estimate of coast wide abundance could not be estimated for the *Alosa* spp. group and was not included in the “other prey” categories. A coast wide assessment of American shad is currently underway and may provide additional information that can be used to develop an abundance estimate. The shad assessment will be done on a river system specific basis and the quality of shad abundance data for Atlantic coast river systems is highly variable and may preclude development of a coast wide abundance estimate.

A coastal bay anchovy abundance estimate was developed using data from the New Jersey Ocean Trawl Survey along with a number of other fishery independent surveys – MD seine survey, MD coastal bay survey, VIMS seine and trawl surveys, DE trawl survey, NJ Delaware River seine survey and the SEAMAP survey.

New prey type selectivity ranks and spatial overlap indices were developed following quantitative algorithms.

Long-term

Two long-term recommendations from the ASMFC MSVPA-X Internal Review regarding data improvement have been addressed. Collection of diet data for adults of all three MSVPA-X predator species for the winter season off of Cape Hatteras, North Carolina has been initiated between the SEAMAP Cooperative Winter Tagging Cruise and VIMS Chesapeake Trophic Interaction Laboratory Services. In addition, an age-structured stock assessment model (ASAP) has been developed and peer reviewed for the coastwide bluefish stock (ASMFC, 2005).

The other long-term research recommendations remain:

- If not achieved before SARC review, add a bluefish age-structure/catch-at-age matrix.
- Adult index for menhaden (e.g., an aerial line transect survey) and other species.
- Obtain population weight-at-age estimates.
- Conduct a coast wide diet and abundance study (i.e., an Atlantic coast “year of the stomach”).
- Collect more diet data for all three MSVPA-X predator species along the entire Atlantic coast, especially for nearshore sites, during all seasons.
- Conduct stomach selectivity research for predator species to improve prey ranking matrix.
- Encourage existing fishery-independent surveys to take regular gut contents.

- Evaluate if striped bass disease (mycobacteria) is correlated with natural mortality (M1) and food availability or if disease is disrupting striped bass feeding and causing starvation. The panel noted that if disease affects striped bass feeding in recent years, then using historical striped bass diet data might bias striped bass consumption in the model output.
- Estimate carrying capacity for the system to evaluate what model estimates/suggests for carrying capacity.
- Improve estimates of biomass for prey species on coast wide basis.
- Conduct a parallel comparison with ICES MSVPA model on a system that has the necessary data collected (Georges Bank or the North Sea) to identify the differences in results.
- Explore the ability to add other predators to model (birds, mammals, other fish, other systems).
- Explore the utility of implementing the Williamson spatial overlap index in the model.
- Investigate type II and type III feeding responses of the MSPVPA-X species in field studies.

5.1.3 Recommendations for Base Run & Sensitivity Analyses

The recommendations from the MSVPA-X Internal Peer Review regarding the tasks to necessary to develop a base run, conduct sensitivity analyses in the retrospective model, and to test the forward projecting model were addressed and covered in detail earlier in this report (see Chapters 1, 2, and 3 for additional information).

5.1.4 Recommendations for Forecast Projection Module (Still under development)

- Determine the affect and sensitivity of the model to the removal of all fishing pressure from system
- Insert recovery benchmarks
- Explore options for adaptive management framework with stock-recruitment options

REFERENCES

- Andersen, K.P. and E. Ursin. 1977. A multispecies extension to the Beverton and Holt theory of fishing, with accounts of phosphorous circulation and primary production. Medd. Dan. Fisk. Havunders N.S. 7: 319-435.
- Atlantic States Marine Fisheries Commission (ASMFC). 2000. American lobster stock assessment report. ASMFC Stock Assessment Report No. 00-01. Washington, D.C.
- Atlantic States Marine Fisheries Commission (ASMFC). 2003. Stock Assessment Report for Atlantic Striped Bass: Catch-at-Age Based VPA & Tag Release/Recovery Based Survival Estimation. Report# SBTC-2003-3. Washington, D.C.
- Atlantic States Marine Fisheries Commission (ASMFC). 2004a. Atlantic Menhaden Stock Assessment Report for Peer Review. ASMFC Stock Assessment Report No. 04-01 (Supplemental). Washington, D.C.
- Buckel, J.A. and D.O. Conover. 1997. Movements, feeding periods, and daily ration of piscivorous young of the year bluefish in the Hudson River estuary. Fish. Bull. 95: 665-679.
- Buckel, J.A., M.J. Fogarty and D.O. Conover. 1999. Foraging habits of bluefish, *Pomatomus saltatrix*, on the U.S. east coast continental shelf. Fish. Bull. 97: 758-775.
- Chesson, J. 1983. The estimation and analysis of preference and its relationship to foraging models. Ecology 64: 1297-1304.
- Cowan, D.F. 1999. A method for assessing relative abundance, size distribution, and growth of recently settled and early juvenile lobsters (*Homarus americanus*) in the lower intertidal zone. Journal of Crustacean Biology 19(4): 738-751.
- Durbin, E.G., A.G. Durbin, A.E. Langton and R.E. Bowman. 1983. Stomach contents of silver hake and Atlantic cod and estimation of their daily rations. Fish. Bull. U.S. 81: 437-454.
- Eggleston, D.B., E.G. Johnson and J.E. Hightower. 2004. Population Dynamics and Stock Assessment of the blue crab in North Carolina. Final report for contracts 99-FEG-10 and 00-FEG-11 to the North Carolina Fishery Resource Grant Program, North Carolina Sea Grant, and the North Carolina Department of Environmental Health and Natural Resources, Division of Marine Fisheries.
- Elliot, J.M. and L. Persson. 1978. The estimation of daily rates of food consumption for fish. J. Anim. Ecol. 47: 977-990.
- Gislason, H. and Th. Helgason. 1985. Species interactions in assessment of fish stocks with special application to the North Sea. Dana 5: 1-44.

- Gulland, J.A. 1983. Fish stock assessment: a manual of basic methods. John Wiley & Sons, New York.
- Hartman, K.J. and S.B. Brandt. 1995. Trophic resource partitioning, diets, and growth of sympatric estuarine predators. Trans. Am. Fish. Soc. 124: 520-537.
- Helgason, Th. and H. Gislason. 1979. VPA-analysis with species interaction due to predation. ICES C.M. 1979/G:52, 10 pp.
- Hilden, M. 1988. Significance of the functional response of predators to changes in prey abundance in multispecies virtual population analysis. Can. J. Fish. Aquat. Sci. 45: 89-96.
- Holling, C.S. 1965. The functional response of predators to prey density and its role in mimicry and population regulation. Mem. Entomol. Soc. Can. 45:1-60.
- Juanes, F., J.A. Buckel and F.S. Scharf. 2001. Predatory behavior and selectivity of a primary piscivore: comparison of fish and non-fish prey. Mar. Ecol. Prog. Ser. 217: 157-165.
- Kahn, D.M. 2002a. Stock Assessment of Weakfish through 2000, including estimates of stock size on January 1, 2001. A Report to the Weakfish Technical Committee of the Atlantic States Marine Fisheries Commission.
- Kahn, D.M. 2002b. Weakfish growth analysis, based on 2000 samples from point net and long haul seine in Chesapeake Bay and Pamlico sound. Report to the ASMFC Weakfish Technical Committee. 21 June 2002.
- Kahn, D.M. and T.E Helser. 2005. Abundance, dynamics and mortality rates of the Delaware Bay stock of blue crabs, *Callinectes sapidus*. J. Shellfish Res. *In press*.
- Lee, L.M. 2003. Population assessment and short-term stock projections of the U.S. East Coast bluefish, *Pomatomus saltatrix*, stock. Report to the Atlantic States Marine Fisheries Commission and Mid-Atlantic Fishery Management Council Monitoring Committee. p. 1 – 22.
- Livingston, P.A. and J. Juado-Molina. 2000. A multispecies virtual population analysis of the eastern Bering Sea. ICES J. Mar. Sci. 57: 294-300.
- Lou, J. and S.B. Brandt. 1993. Bay anchovy production and consumption in mid- Chesapeake Bay based upon a bioenergetics model and acoustic measurements of fish abundance. Mar. Ecol. Prog. Ser. 98: 223 – 236.
- Magnusson, K.G. 1995. An overview of the multispecies VPA – theory and applications. Rev. Fish. Biol. and Fisheries 5: 195-212.

- Merriner, J.V. 1975. Food Habits of the Weakfish in North Carolina Waters. Ches. Sci. 16: 74-76
- Northeast Fisheries Science Center (NEFSC). 1997. Report of the 23rd Northeast Regional Stock Assessment Workshop (23rd SAW): Stock Assessment Review Committee (SARC) Consensus Summary of Assessments. NEFSC. Ref. Doc. 97-05. 191 p.
- Northeast Fisheries Science Center (NEFSC). 1998. 26th Northeast Regional Stock Assessment Workshop: Stock Assessment Review Committee (SARC) Consensus Summary of Assessments. NEFSC Reference Document 98-03.
- Northeast Fisheries Science Center (NEFSC). 34th Northeast Regional Stock Assessment Review Committee (SARC) Consensus Summary of Assessments. NEFSC Reference Document 02-06. 346 p.
- Northeast Fisheries Science Center (NEFSC). 2003. 37th Northeast Regional Stock Assessment Workshop (37th SAW) Stock Assessment Review Committee (SARC) Consensus Summary of Assessments NEFSC Reference Document 03-16. 597 p.
- Northeast Fisheries Science Center (NEFSC). 2004. 38th Northeast Regional Stock Assessment Workshop (38th SAW) Stock Assessment Review Committee (SARC) Consensus Summary of Assessments. NEFSC Reference Document 04-03. 246 p.
- Northeast Fisheries Science Center (NEFSC). 2005. 41st Northeast Regional Stock Assessment Workshop (41st SAW) 41st Assessment Report: Bluefish Assessment Report. NEFSC Reference Document 05-14. 237 p.
- Nelson, G.A., B.C. Chase and J. Stockwell. 2003. Food habits of Striped Bass (*Morone saxatilis*) in coastal waters of Massachusetts. J. Northw. Atl. Fish. Sci. 32:1-25.
- Newberger, T.A. and E.D. Houde. 1995. Population biology of bay anchovy, *Anchoa mitchilli*, in the mid-Chesapeake Bay. Mar. Ecol. Prog. Ser. 116: 25 – 37.
- Overholtz, W.J., L. D. Jacobson, G.D. Melvin, M. Cieri, M. Power, D. Libby and K. Clark. 2003. Stock assessment of the Gulf of Maine - Georges Bank Atlantic herring Complex. NEFSC Reference Document 04-06, pp. 1-290.
- Pope, J.G. 1979. A modified cohort analysis in which constant mortality is replaced by estimates of predation levels. ICES CM 1979/H:16, 8 pp.
- Pope, J.G. 1991. The ICES Multispecies Assessment Working Group: evolution, insights, and future problems. ICES Mar. Sci. Symp. 193: 22-33.
- Rilling, G.C. and E.D. Houde. 1999. Regional and temporal variability in distribution and abundance of bay anchovy (*Anchoa mitchilli*) eggs, larvae, and adult biomass in Chesapeake Bay. Estuaries 22: 1096 – 1109.

- Scharf, F.S., J.A. Buckel, F. Juanes and D.O. Conover. 1998. Predation by juvenile piscivorous bluefish (*Pomatomus saltatrix*): the influence of prey to predator size ratio and prey type on predator capture success and prey profitability. Can. J. Fish. Aquat. Sci. 55: 1695-1703.
- Sharov, A.F., J.H. Vølstad, G R. Davis, B.K. Davis, R.N. Lipcius and M.M. Montane. 2002. Abundance and exploitation rate of the blue crab (*Callinectes sapidus*). Chesapeake Bay. Bull. Mar. Sci. 72(2) : 543 - 565.
- Shepherd, J.G. 1982. A versatile new stock-recruitment relationship for fisheries and the construction of sustainable yield curves. J. Cons. Int. Explor. Mer. 40: 67-75
- Shepherd, J.G. 1999. Extended survivors analysis: An improved method for the analysis of catch-at-age data and abundance indices. ICES J. Mar. Sci. 56: 584-591.
- Smith, J.W. 1994. Biology and fishery for Atlantic thread herring, *Opisthonema oglinum*, along the North Carolina coast. Marine Fisheries Review 56(4):1-7.
- Tsou, T-S and J. S. Collie. 2001. Estimating predation mortality in the Georges Bank fish community. Can. J. Fish. Aquat. Sci. 58: 908-922.
- Vaughn, D.S., J.W. Smith and E.H. Williams. 2002. Analyses on the status of the Atlantic Menhaden Stock. Report to ASMFC Menhaden Technical Committee. 12 July, 2002. 60 pp.
- Walter, J.F. and H.M. Austin. 2003. Diet composition of large striped bass (*Morone saxatilis*) in Chesapeake Bay. Fish. Bull. U.S. 101: 414-423.
- Williamson, C.E. 1993. Linking predation risk models with behavioral mechanisms: Identifying population bottlenecks. Ecology 74: 320-331.

TABLES

Table D.1. Catch at age of Atlantic menhaden (millions) from 1982-2002. The period from 1985-2002 includes combined landings from the reduction and bait components of the fishery (ASMFC, 2004a).

	Age						
Year	0	1	2	3	4	5	6+
1982	114.1	919.4	1739.6	379.7	16.3	5.8	0.8
1983	964.4	517.2	2293.1	114.3	47.4	5.0	0.2
1984	1294.2	1024.2	892.1	271.5	50.3	15.2	0.5
1985	637.6	1088.7	1254.4	72.2	49.1	7.5	1.9
1986	98.7	237.0	1547.8	81.0	28.4	7.2	1.3
1987	43.2	518.4	1615.8	186.3	43.9	3.5	1.0
1988	339.2	297.7	1186.7	343.6	94.2	8.5	0.9
1989	150.1	1172.6	1194.0	141.3	64.0	13.0	0.5
1990	308.5	153.5	1589.4	141.7	59.2	13.6	0.7
1991	882.2	1051.9	982.0	294.1	59.3	12.3	2.5
1992	400.1	744.5	834.6	108.3	72.8	12.7	2.3
1993	68.3	391.4	1015.1	187.4	30.7	5.5	0.6
1994	88.8	289.1	911.0	194.6	86.9	10.4	0.4
1995	56.9	559.1	703.0	347.0	87.0	4.5	0.1
1996	33.8	211.8	716.5	159.3	34.0	2.2	0.1
1997	25.2	251.6	456.9	263.0	63.4	12.0	1.8
1998	75.4	189.2	578.5	157.2	96.1	13.0	1.5
1999	194.1	305.1	508.5	114.8	42.0	5.5	0.8
2000	78.1	127.4	399.7	133.2	21.9	3.3	0.3
2001	23.1	46.1	398.9	266.9	22.9	1.5	0.3
2002	178.2	216.5	296.6	179.9	26.5	1.4	0.2

Table D.2. Coastwide age-0 menhaden CPUE index in state seine surveys (ASMFC, 2004a).

	Age
Year	0
1982	5.005
1983	4.554
1984	5.189
1985	4.936
1986	4.962
1987	3.743
1988	4.774
1989	4.150
1990	4.298
1991	4.271
1992	3.285
1993	2.585
1994	3.118
1995	2.765
1996	2.572
1997	2.817
1998	2.938
1999	2.662
2000	2.308
2001	3.021
2002	2.481

Table D.3. Potomac River pound net CPUE indices for Atlantic menhaden. The aggregated biomass index (ASMFC, 2004a) was disaggregated by applying a selectivity curve (0.25 - age 1, 1.0 - age 2, 0.25- age 3) and converting catch in pounds to numbers based upon annual weight-at-age-data.

Year	Age		
	1	2	3
1982	885.0	1773.8	270.9
1983	825.3	1550.1	237.7
1984	555.4	966.2	147.5
1985	574.7	976.5	147.7
1986	477.9	853.5	128.6
1987	780.2	1487.5	228.4
1988	822.8	1464.3	220.7
1989	386.3	772.6	120.5
1990	172.5	352.9	62.1
1991	223.9	477.7	81.9
1992	237.3	452.0	78.3
1993	336.7	743.4	131.4
1994	284.4	486.8	78.1
1995	248.8	443.3	75.5
1996	183.9	288.4	46.9
1997	202.4	347.0	55.8
1998	124.4	249.6	40.0
1999	158.9	292.4	46.9
2000	162.8	275.2	46.1
2001	78.4	163.2	29.1
2002	82.1	153.9	27.4

Table D.4. Size-at-age of Atlantic menhaden (mm) from 1982-2002 calculated from five-year averages of annual von Bertalanffy growth curve parameters (ASMFC, 2004a)

	Age						
Year	0	1	2	3	4	5	6
1982	70.28	137.68	189.81	230.12	261.30	285.41	304.05
1983	70.28	137.68	189.81	230.12	261.30	285.41	304.05
1984	70.28	137.68	189.81	230.12	261.30	285.41	304.05
1985	70.28	137.68	189.81	230.12	261.30	285.41	304.05
1986	70.28	137.68	189.81	230.12	261.30	285.41	304.05
1987	83.14	152.39	203.33	240.81	268.38	288.66	303.58
1988	83.14	152.39	203.33	240.81	268.38	288.66	303.58
1989	83.14	152.39	203.33	240.81	268.38	288.66	303.58
1990	83.14	152.39	203.33	240.81	268.38	288.66	303.58
1991	83.14	152.39	203.33	240.81	268.38	288.66	303.58
1992	49.43	153.12	216.01	254.15	277.29	291.32	299.83
1993	49.43	153.12	216.01	254.15	277.29	291.32	299.83
1994	49.43	153.12	216.01	254.15	277.29	291.32	299.83
1995	49.43	153.12	216.01	254.15	277.29	291.32	299.83
1996	49.43	153.12	216.01	254.15	277.29	291.32	299.83
1997	66.51	163.94	227.16	268.19	294.81	312.09	323.30
1998	66.51	163.94	227.16	268.19	294.81	312.09	323.30
1999	66.51	163.94	227.16	268.19	294.81	312.09	323.30
2000	66.51	163.94	227.16	268.19	294.81	312.09	323.30
2001	66.51	163.94	227.16	268.19	294.81	312.09	323.30
2002	66.51	163.94	227.16	268.19	294.81	312.09	323.30

Table D.5. Weight-at-age of Atlantic menhaden (g) from 1982-2002 calculated from five-year averages of annual length-weight regression parameters (ASMFC, 2004a)

	Age						
Year	0	1	2	3	4	5	6
1982	4.76	38.89	106.05	193.58	287.92	379.36	462.30
1983	4.76	38.89	106.05	193.58	287.92	379.36	462.30
1984	4.76	38.89	106.05	193.58	287.92	379.36	462.30
1985	4.76	38.89	106.05	193.58	287.92	379.36	462.30
1986	4.76	38.89	106.05	193.58	287.92	379.36	462.30
1987	9.16	64.22	162.29	279.55	396.07	500.58	588.62
1988	9.16	64.22	162.29	279.55	396.07	500.58	588.62
1989	9.16	64.22	162.29	279.55	396.07	500.58	588.62
1990	9.16	64.22	162.29	279.55	396.07	500.58	588.62
1991	9.16	64.22	162.29	279.55	396.07	500.58	588.62
1992	1.41	51.84	155.14	260.43	343.73	402.26	440.91
1993	1.41	51.84	155.14	260.43	343.73	402.26	440.91
1994	1.41	51.84	155.14	260.43	343.73	402.26	440.91
1995	1.41	51.84	155.14	260.43	343.73	402.26	440.91
1996	1.41	51.84	155.14	260.43	343.73	402.26	440.91
1997	5.18	93.27	265.27	451.61	611.63	734.09	821.99
1998	5.18	93.27	265.27	451.61	611.63	734.09	821.99
1999	5.18	93.27	265.27	451.61	611.63	734.09	821.99
2000	5.18	93.27	265.27	451.61	611.63	734.09	821.99
2001	5.18	93.27	265.27	451.61	611.63	734.09	821.99
2002	5.18	93.27	265.27	451.61	611.63	734.09	821.99

Table D.6. Commercial and recreational catch at age matrix for striped bass (ASMFC, 2003).

	Age												
Year	1	2	3	4	5	6	7	8	9	10	11	12	13+
1982	1.810	105.555	256.699	220.835	58.429	19.180	24.213	16.802	11.692	10.593	11.017	13.668	15.671
1983	3.625	110.327	178.236	193.141	150.019	39.286	18.713	4.125	2.895	3.709	4.581	5.644	13.548
1984	5.563	542.751	302.698	82.425	60.374	51.680	18.280	4.668	2.117	2.078	0.693	0.336	11.139
1985	1.311	72.529	101.959	40.483	58.703	43.106	43.522	17.283	6.351	3.404	1.043	0.827	10.321
1986	11.332	21.009	63.841	132.875	49.899	31.972	20.367	23.997	9.191	5.260	3.355	1.564	10.116
1987	1.368	10.915	37.629	51.422	67.260	25.041	13.204	6.490	6.384	2.982	1.448	1.968	12.916
1988	2.566	30.882	41.755	63.222	107.100	97.917	40.598	24.411	13.995	5.773	3.676	3.251	9.560
1989	0.729	35.994	79.665	68.244	104.896	95.437	45.645	21.026	10.423	3.758	3.234	1.965	8.848
1990	2.123	46.231	124.469	187.830	173.215	165.168	104.079	67.781	20.695	7.256	5.061	3.507	13.671
1991	1.792	72.836	145.252	208.716	161.950	101.438	91.311	82.920	58.757	24.090	14.173	2.755	22.330
1992	2.914	45.769	199.651	189.212	177.132	109.523	62.419	67.781	58.384	44.782	9.301	4.070	15.942
1993	0.287	69.633	185.306	327.330	288.512	185.379	86.551	67.337	82.587	76.145	41.133	9.327	17.457
1994	5.665	145.422	348.825	290.641	367.749	232.389	135.432	86.698	99.882	80.962	36.013	22.302	14.625
1995	3.838	426.821	459.079	447.829	391.341	470.669	204.809	190.869	151.640	88.555	52.246	16.455	14.908
1996	0.465	92.673	639.954	634.993	533.768	457.572	436.529	208.439	140.109	67.719	42.043	44.663	20.621
1997	2.533	285.466	486.449	850.321	615.973	593.847	405.508	372.316	200.317	120.479	59.642	29.987	24.850
1998	26.421	183.404	485.409	706.672	1125.019	510.938	280.434	265.002	215.493	113.842	95.070	45.172	65.493
1999	9.210	116.452	433.400	656.249	651.804	714.112	336.562	226.801	193.497	138.519	97.623	45.054	45.696
2000	37.977	323.977	419.860	989.188	1021.208	780.437	738.105	311.870	160.636	141.488	59.631	29.301	30.751
2001	34.741	161.922	431.514	605.354	830.556	696.646	576.745	480.387	205.831	119.546	102.964	49.634	47.952
2002	25.189	213.284	306.307	462.780	569.670	741.606	514.862	355.018	276.601	106.444	87.934	48.450	61.888

Table D.7 Weight (kg) and size at age (cm) of striped bass estimated from a von Bertalanffy curve fit to state specific length at age data. von Bertalanffy parameters are: $L_{inf} = 158.4$, $k = 0.075$, $T_0 = -0.9855$.

Age	Weight (kg)	Length (cm)
0	0.078	11.29
1	0.156	21.92
2	0.756	31.78
3	1.274	40.93
4	2.079	49.41
5	2.719	57.29
6	3.66	64.6
7	4.79	71.37
8	5.657	77.66
9	6.528	83.50
10	7.912	88.91
11	9.116	93.93
12	10.24	98.59
13+	11.712	102.91

Table D.8. Catch-at-age of weakfish (thousands of fish) from 1982-2000 (Kahn, 2002a).

Year	Age					
	1	2	3	4	5	6+
1982	7893	11794	5419	2774	720	639
1983	6431	12100	5702	2775	567	424
1984	7533	13892	6437	3040	483	254
1985	12790	10690	3134	1165	212	55
1986	17032	15000	4815	1816	262	52
1987	14976	13533	4254	1478	144	11
1988	6952	15443	10456	6058	1042	69
1989	2246	4796	4307	2918	625	84
1990	8895	4537	2012	1200	590	89
1991	9104	5460	2686	1355	459	56
1992	4306	5682	2176	1252	527	65
1993	3769	5770	2126	1133	400	48
1994	3166	2876	3001	1362	199	38
1995	3471	3095	3379	1574	196	54
1996	1482	2053	4073	2955	1334	98
1997	970	1553	2563	5037	1469	397
1998	835	1709	3535	1904	2827	871
1999	805	1148	2076	3058	702	1123
2000	934	1046	1663	1754	1822	466

Table D.9. Weight (kg) and size (cm) at age for weakfish at the beginning of each year based on annual Von Bertalanffy growth curves and length-weight regressions (Kahn, 2002a).

Age	Weight (kg)	Length (cm)
0	0.027	5.3
1	0.111	17.3
2	0.255	26.0
3	0.480	33.3
4	0.755	39.6
5	1.057	44.9
6+	1.368	49.5

Table D.10. Regional densities (gm-2) of benthic invertebrate taxa provided in Wigley and Theroux (1981) and Theroux and Wigley (1998).

Taxon	Georges Bank/ Gulf of Maine (Area = 84,006 km ²)	Southern New England (Area = 14,805 km ²)	Mid-Atlantic (Area = 17,203 km ²)	Chesapeake Bay (Area = 7,913 km ²)	North Carolina (Area = 26,455 km ²)
Gammarids	5.9	5.51	4.7	4.7	4.7
Isopoda	0.94	0.95	0.94	0.95	0.35
Polychaetes	8.2	39.1	22.2	22.2	22.2
Total Biomass (000 Metric Tons)	1,263	674	479	220	720

Table D.11. Estimated total biomass (mt) of blue crabs based upon stock assessment documents.

Year	DE Bay	Chesapeake Bay	North Carolina	Total Biomass (mt)
1982	11,142.22	40,156.55	34,988.2	86287.0
1983	3,548.14	42,130.65	31,724.5	77403.3
1984	4,640.41	34,264.70	29,821.5	68726.6
1985	13,233.29	33,405.84	27,053.0	73692.2
1986	25,147.32	35,408.78	21,670.4	82226.5
1987	8,136.74	32,636.71	29,575.8	70349.3
1988	12,883.98	33,787.20	32,479.7	79150.9
1989	17,796.26	37,676.11	89,149.5	144621.9
1990	34,994.84	38,568.56	35,230.4	108793.8
1991	6,795.04	53,278.71	81,223.2	141297.0
1992	19,848.34	38,230.46	31,149.7	89228.5
1993	19,946.08	41,868.20	40,069.5	101883.8
1994	29,721.50	24,629.33	31,635.8	85986.6
1995	38,529.63	20,025.25	28,425.7	86980.6
1996	13,773.82	26,916.03	23,517.2	64207.0
1997	17,238.11	18,884.66	43,653.4	79776.2
1998	44,001.66	23,560.38	32,089.8	99651.8
1999	22,642.30	12,525.48	30,418.0	65585.8
2000	33,719.37	15,024.27	23,052.5	71796.1
2001	29,954.37	13,546.09	20,050.8	63551.2
2002	15,330.24	16,822.63	31,839.5	63992.4

Table D.12. Absolute abundance (millions) of recruit and postrecruit lobster in the Gulf of Maine.

Year	Recruits	Postrecruits	Total
1982	27.57	9.19	36.76
1983	32.28	13.86	46.14
1984	15.24	22.37	37.61
1985	31.89	15.5	47.39
1986	27.71	22.06	49.77
1987	14.01	23.99	38
1988	33.51	14.25	47.76
1989	37.04	20.98	58.02
1990	41.67	26.5	68.17
1991	30.18	29.02	59.2
1992	34.33	23.91	58.24
1993	38.76	27.4	66.16
1994	71.55	31.02	102.57
1995	44.85	54.45	99.3
1996	70.23	53.11	123.34
1997	54.49	59.54	114.03

Table D.13. Absolute abundance (millions) of recruit and postrecruit lobster in the Cape Cod and Long Island areas.

Year	Recruits	Postrecruits	Total
1982	1.58	1.998	3.578
1983	1.696	1.547	3.243
1984	2.54	1.309	3.849
1985	1.681	1.437	3.118
1986	3.481	0.969	4.45
1987	1.222	2.282	3.504
1988	1.855	1.511	3.366
1989	3.928	0.85	4.778
1990	3.914	1.536	5.45
1991	1.455	2.283	3.738
1992	3.383	1.743	5.126
1993	1.466	2.217	3.683
1994	2.791	0.672	3.463
1995	3.451	1.387	4.838
1996	6.171	2.719	8.89
1997	6.18	4.789	10.969

Table D.14. Estimated biomass (mt) of lobster recruits.

Year	Gulf of Maine	Cape Cod and LI	Total
1982	1,582.0	90.7	1,672.6
1983	1,852.2	97.3	1,949.5
1984	874.5	145.7	1,020.2
1985	1,829.8	96.5	1,926.3
1986	1,590.0	199.7	1,789.7
1987	803.9	70.1	874.0
1988	1,922.8	106.4	2,029.2
1989	2,125.4	225.4	2,350.7
1990	2,391.0	224.6	2,615.6
1991	1,731.7	83.5	1,815.2
1992	1,969.9	194.1	2,164.0
1993	2,224.0	84.1	2,308.2
1994	4,105.5	160.1	4,265.7
1995	2,573.5	198.0	2,771.5
1996	4,029.8	354.1	4,383.9
1997	3,126.6	354.6	3,481.2
average	2,170.8	167.8	2,338.6

Table D.15. Seasonal and regional trawl survey catch per tow reported in Stehlik *et al.* (1991).

Taxon	Georges Bank/ Gulf of Maine (Area = 84,006 km ²)	Southern New England (Area = 14,805 km ²)	Mid-Atlantic (Area = 17,203 km ²)	Chesapeake Bay (Area = 7,913 km ²)	North Carolina (Area = 26,455 km ²)
Rock Crab (Spring)	2.24	22.34	22.34	22.34	0
Rock Crab (Fall)	0.84	1.15	1.15	1.15	0
Jonah (Spring)	0.33	0.08	0.08	0	0
Jonah (Fall)	0.29	0.09	0.09	0	0

Table D.16. Annual landings (mt) summarized by clupeid species and total from sources identified in text. Abundance (mt) is estimated from total annual landings by dividing by F (0.05) as described in text.

Year	HERRING, ATLANTIC	HERRING, ATLANTIC THREAD	SARDINE, SPANISH	SCADS	Grand Total	Abundance
1982	44447.8	38.2			44486.0	889719.8
1983	33229.9	1370.0			34599.9	691998.0
1984	46659.7	1526.4	8.3		48194.4	963888.3
1985	33352.3	1529.1			34881.4	697628.0
1986	40219.4	108.6	1.7	36.4	40366.1	807322.8
1987	49957.2	421.1	1.6	95.3	50475.2	1009503.0
1988	53617.4	563.8	2.1	161.6	54345.0	1086899.3
1989	55842.1	1.5	13.2	125.7	55982.5	1119649.4
1990	55573.5	2584.2	65.9	49.0	58272.6	1165452.3
1991	80165.4	1726.6	14.3	0.1	81906.3	1638126.9
1992	92748.5	2168.8	81.1		94998.4	1899968.5
1993	77056.3	3101.1	48.0	5.4	80210.9	1604217.2
1994	64255.6	3557.3	55.9	3.3	67872.2	1357443.1
1995	106304.9	3961.0	32.9	10.4	110309.2	2206183.1
1996	119118.7	2997.7	90.9	31.5	122238.8	2444775.1
1997	111144.1	6305.0	151.9	55.9	117656.8	2353136.1
1998	99510.0	1397.4	150.2	52.8	101110.5	2022209.1
1999	110265.2	381.3	168.6	42.5	110857.6	2217151.6
2000	106173.1	1931.2	3.2	0.1	108107.6	2162152.8
2001	124260.0	268.5	12.3	0.1	124540.9	2490818.6
2002	93123.9	1249.5	7.5	0.3	94381.2	1887624.3
2003	103781.1	14.4	27.7		103823.2	2076463.4
2004	87324.2				87324.2	1746483.2
Grand Total	1788130.4	37202.6	937.3	670.4	1826940.7	

Table D.17. Seasonal landings (mt) summarized by species and overall proportion by season. Season define by 3-month periods (Jan-Mar, Apr-Jun, Jul-Sep, Oct-Dec).

Season	HERRING, ATLANTIC	HERRING, ATLANTIC THREAD	SARDINE, SPANISH	SCADS	Grand Total	Proportion
1	305798.19	177.4	19	4.1	305998.7	0.168
2	284549.13	514.8	73	36.6	285173.5	0.156
3	733470.37	35296.1	113.4	9	768888.9	0.421
4	464312.71	21.2	2.5	0.8	464337.2	0.255
Grand Total	1788130.4	36009.5	207.9	50.5	1824398.3	1.000

Table D.18. Length composition of Atlantic herring summarized from data for 1982-2004 (pers. comm., Matthew Cieri, Maine DMR).

Total Length (mm)	Frequency	Proportion
<230	253	0.001
230-250	10131	0.040
250-270	40524	0.160
270-290	73449	0.290
290-310	78515	0.310
310-330	37991	0.150
330-350	10131	0.040
350-370	1266	0.005
370-390	253	0.001
Total	252514	1.00

Table D.19. Length and age composition of Atlantic thread herring summarized from data collected between 1982-2002 (pers.comm., Joe W. Smith, SEFSC).

Fork Length (mm)	Frequency	Proportion
120-129	1	0.001
130-139	11	0.011
140-149	95	0.096
150-159	225	0.227
160-169	296	0.299
170-179	249	0.252
180-189	100	0.101
190-199	11	0.011
200-209	2	0.002
Total	990	1.000

Age (yr)	Frequency	Proportion
1	1	0.002
2	11	0.018
3	95	0.151
4	225	0.358
5	296	0.471
	628	0.634

Table D.20. Time series of bay anchovy biomass estimates (mt) for Atlantic coast estuaries and coastal waters and combined during season 2 (spring) and 3 (summer).

Season 2				Season 3			
Year	Estuaries	Coast	Total	Year	Estuaries	Coast	Total
1982	45,754.0	136,810.2	182,564.2	1982	198,930.6	555,016.7	753,947.3
1983	48,283.4	136,810.2	185,093.6	1983	209,927.8	555,016.7	764,944.5
1984	50,454.2	136,810.2	187,264.3	1984	219,366.0	555,016.7	774,382.7
1985	61,795.4	136,810.2	198,605.6	1985	268,675.8	555,016.7	823,692.5
1986	58,527.7	136,810.2	195,337.9	1986	254,468.2	555,016.7	809,484.9
1987	50,706.5	136,810.2	187,516.6	1987	220,462.9	555,016.7	775,479.6
1988	33,382.2	136,810.2	170,192.3	1988	145,139.8	555,016.7	700,156.6
1989	70,142.2	103,160.9	173,303.1	1989	304,966.1	418,507.0	723,473.1
1990	41,061.1	124,354.2	165,415.3	1990	178,526.4	504,484.9	683,011.4
1991	67,817.3	98,229.5	166,046.8	1991	294,857.8	398,501.1	693,358.9
1992	70,667.3	133,228.6	203,895.9	1992	307,249.2	540,486.9	847,736.2
1993	62,564.6	136,810.2	199,374.8	1993	272,020.2	555,016.7	827,036.9
1994	48,157.1	89,310.4	137,467.6	1994	209,378.8	362,318.0	571,696.8
1995	50,924.8	120,611.6	171,536.5	1995	221,412.2	489,301.9	710,714.1
1996	36,013.9	109,687.8	145,701.7	1996	156,582.0	444,985.8	601,567.8
1997	43,518.0	90,873.9	134,391.9	1997	189,208.9	368,660.7	557,869.6
1998	42,997.8	73,458.3	116,456.1	1998	186,946.9	298,008.6	484,955.5
1999	49,790.1	92,748.7	142,538.7	1999	216,478.5	376,266.3	592,744.8
2000	59,745.8	88,964.0	148,709.8	2000	259,764.5	360,912.5	620,677.0
2001	36,354.7	68,741.1	105,095.8	2001	158,064.0	278,871.6	436,935.6
2002	29,202.1	80,801.1	110,003.2	2002	126,965.5	327,796.9	454,762.4
Mean	50,374.3	112,792.9	163,167.2	Mean	219,018.7	457,582.7	676,601.3

Table D.21. References for regional diet composition data for striped bass.

Reference	Region	Age Classes	Seasons
Hartman & Brandt 1995a	Chesapeake Bay	0, 1-2, 3-5	1-4
Walter & Austin 2003	Chesapeake Bay	6+	1-4
Walter <i>et al.</i> 2003	Chesapeake Bay	1-3, 4-7, 8+	1-4
Cooper 1998	North Carolina	0	3-4
Walter <i>et al.</i> 2003	North Carolina	1-3, 4-7, 8+	1-4
NEFSC-Food Habits Database	North Carolina	4-7, 8+	2
NEFSC-Food Habits Database	Mid-Atlantic	1-3, 4-7	2
Walter <i>et al.</i> 2003	New England	1-3, 4-7, 8+	1-4
NEFSC-Food Habits Database	New England	1-3, 4-7, 8+	2,4
Nelson et al. 2003	Gulf of Maine	4-7, 8+	3

Table D.22. Quantitative electivity values for striped bass in Chesapeake Bay.

Age Class	Season	Anch.	Invert.	Crust.	Macro-zooplankton	Med. Forage	Menhaden	Sciaenids
Age 0	1	0.0000	0.9896	0.0000	0.0104	0.0000		0.0000
Age 0	2	0.0000	0.9896	0.0000	0.0104	0.0000	0.0000	0.0000
Age 0	3	0.0181	0.0283	0.0272	0.1265	0.7999	0.0000	0.0000
Age 0	4	0.4020	0.0279	0.1870	0.3831	0.0000	0.0000	0.0000
Age 1-2	1	0.0378	0.3401	0.0000	0.0811	0.4066		0.1345
Age 1-2	2	0.0070	0.0421	0.0324	0.0406	0.2807	0.0000	0.5972
Age 1-2	3	0.0355	0.0067	0.7533	0.1437	0.0000	0.0447	0.0161
Age 1-2	4	0.0230	0.0026	0.0582	0.0764	0.0000	0.4669	0.3728
Age 3-5	1	0.0017	0.0002	0.0000	0.0000	0.9765		0.0216
Age 3-5	2	0.0018	0.0658	0.0302	0.0004	0.4388	0.0082	0.4547
Age 3-5	3	0.0404	0.2180	0.0769	0.0000	0.4682	0.1965	0.0000
Age 3-5	4	0.0005	0.0000	0.0191	0.0027	0.0982	0.8796	0.0000
Age 6-7	1	0.0016	0.0007	0.0021	0.0000	0.9748		0.0208
Age 6-7	2	0.0000	0.0005	0.0323	0.0000	0.9319	0.0096	0.0257
Age 6-7	3	0.0043	0.0036	0.9653	0.0000	0.0143	0.0125	0.0000
Age 6-7	4	0.0020	0.0012	0.0089	0.0000	0.4021	0.0423	0.5434
Age 8+	1	0.0000	0.0000	0.0004	0.0000	0.9996		0.0000
Age 8+	2	0.0000	0.0000	0.0239	0.0000	0.9475	0.0067	0.0218
Age 8+	3	0.0000	0.0000	0.0047	0.0000	0.9301	0.0652	0.0000
Age 8+	4	0.0114	0.0058	0.0175	0.0000	0.4505	0.0744	0.4403

Table D.23. Ranked type preference values for Striped Bass used as inputs in the MSVPA-X application.

Age	Anchovies	Inverts.	Crust.	Herrings	Macro - zooplankton	Medium Forage	Menhaden	Sciaenids
0	0	1	0	0	2	0	0	0
1	7	5	1	0	6	4	3	2
2	7	5	1	0	6	4	3	2
3	6	3	4	0	7	1	2	5
4	7	5	3	6	8	1	2	4
5	6	5	3	8	7	1	2	4
6	5	8	3	7	6	1	2	4
7	6	7	2	5	0	1	4	3
8	6	7	2	5	0	1	4	3
9	6	7	2	4	0	1	5	3
10	6	7	2	4	0	1	5	3
11	6	7	2	3	0	1	5	4
12	6	7	2	3	0	1	5	4
13+	6	7	2	3	0	1	5	4

Table D.24. Available references for diet information for weakfish.

Reference	Region	Age Classes	Seasons
Hartman & Brandt 1995a	Chesapeake Bay	0, 1, 2-3	2-4
Merriner 1975	North Carolina	0-5	3-4
NEFSC-Food Habits Database	North Carolina	1-2, 3+	2, 4
NEFSC-Food Habits Database	Mid-Atlantic	1-2, 3+	4
NEFSC-Food Habits Database	New England	1-2, 3+	4

Table D.25. Type preference ranks derived from available diet information for weakfish.

Age	Anchovies	Inverts.	Crust.	Herrings	Macro - zooplankton	Medium Forage	Menhaden	Sciaenids
0	3	2	0	0	1	0	0	0
1	2	7	6	0	5	4	1	3
2	4	6	5	0	7	3	1	2
3	6	8	5	2	7	4	3	1
4	6	8	4	2	7	5	3	1
5	6	8	4	2	7	5	1	3
6+	5	8	4	2	7	6	3	1

Table D.26. Available references for diet information for bluefish.

Reference	Region	Size Classes	Seasons
Hartman & Brandt 1993a	Chesapeake Bay	1-3	3
NEFSC-Food Habits Database	North Carolina	1-3	2, 4
NEFSC-Food Habits Database	Mid-Atlantic	1-3	2,4
NEFSC-Food Habits Database	New England	1-3	2,4
Buckel and Conover 1999	New England	1	3
Juanes <i>et al.</i> 2001	New England	1	3
NEFSC-Food Habits Database	Gulf of Maine	1-3	2,4

Table D.27. Type preference ranks derived from available diet information for bluefish.

Size	Anchovies	Inverts.	Crust.	Herrings	Macro - zooplankton	Medium Forage	Menhaden	Sciaenids
1	2	6	5	7	8	1	4	3
2	7	8	6	2	5	1	4	3
3	6	7	4	3	8	1	5	2

Table D.28. Surface area and states included in strata used for spatial analyses.

Region	Area (km²)	States
North Carolina	26,455	North Carolina
Chesapeake Bay	7,912	Virginia and Maryland
Mid-Atlantic	17,202	Offshore VA and MD, New Jersey, Delaware
Southern New England	14,805	New York, Connecticut, Rhode Island
Gulf of Maine	84,006	Massachusetts, Maine

Table D.29. Seasonal spatial overlap values for weakfish.

Season	Prey	Age 1	Age 2	Age 3	Age 4	Age 5	Age 6+
1	Menhaden	0.9282	0.9631	0.9725	0.9733	0.8853	0.9091
1	Anchovy	0.3718	0.3369	0.3275	0.3267	0.4147	0.3909
1	Crustaceans	0.4617	0.4267	0.4173	0.4165	0.4781	0.4480
1	Inverts	0.2808	0.2515	0.2421	0.2413	0.3293	0.3055
1	Herrings	0.0965	0.0792	0.0698	0.0690	0.1570	0.1332
1	Macrozooplankton	0.2291	0.2128	0.2034	0.2027	0.2906	0.2669
1	Medium Forage Fish	0.4083	0.3734	0.3640	0.3632	0.4512	0.4274
1	Sciaenids	0.9742	0.9370	0.9237	0.9208	0.9296	0.9171
2	Menhaden	0.8512	0.7579	0.5577	0.5275	0.2941	0.2162
2	Anchovy	0.6476	0.8507	0.6712	0.6461	0.4321	0.3543
2	Crustaceans	0.5811	0.8129	0.6999	0.6577	0.4245	0.3467
2	Inverts	0.3132	0.4238	0.4365	0.4537	0.3749	0.3888
2	Herrings	0.1418	0.2378	0.2505	0.2677	0.3495	0.3690
2	Macrozooplankton	0.2744	0.3439	0.3567	0.3738	0.3197	0.3172
2	Medium Forage Fish	0.3394	0.4997	0.4909	0.5030	0.3699	0.3282
2	Sciaenids	0.9109	0.5792	0.3878	0.3506	0.1825	0.1046
3	Menhaden	0.8709	0.6039	0.4012	0.3656	0.2282	0.1750
3	Anchovy	0.5898	0.7067	0.5040	0.4899	0.3525	0.2993
3	Crustaceans	0.5234	0.6805	0.5216	0.4823	0.3449	0.2916
3	Inverts	0.2554	0.3265	0.3266	0.3514	0.3899	0.3872
3	Herrings	0.0001	0.0018	0.0023	0.0028	0.0048	0.0054
3	Macrozooplankton	0.2425	0.2853	0.2854	0.3103	0.2859	0.2621
3	Medium Forage Fish	0.2864	0.3987	0.3988	0.4236	0.4155	0.3623
3	Sciaenids	0.9456	0.5902	0.3643	0.3244	0.1851	0.1312
4	Menhaden	0.7381	0.7341	0.5476	0.5082	0.2459	0.1814
4	Anchovy	0.7310	0.8516	0.6965	0.6757	0.4299	0.3654
4	Crustaceans	0.6646	0.8923	0.7239	0.6846	0.4222	0.3577
4	Inverts	0.3278	0.4239	0.4378	0.4564	0.4072	0.4151
4	Herrings	0.0001	0.0012	0.0018	0.0019	0.0020	0.0021
4	Macrozooplankton	0.2762	0.3440	0.3580	0.3765	0.3376	0.3282
4	Medium Forage Fish	0.3501	0.4874	0.5013	0.5199	0.4794	0.4284
4	Sciaenids	0.6308	0.6817	0.5344	0.4950	0.2325	0.1680

Table D.30. Seasonal spatial overlap values for bluefish.

Season	Prey	Size1	Size2	Size3
1	Menhaden	0.9939	0.6707	0.9125
1	Anchovy	0.3062	0.5934	0.3875
1	Crustaceans	0.3960	0.7119	0.4773
1	Inverts	0.2208	0.4361	0.3021
1	Herrings	0.0484	0.2501	0.1298
1	Macrozooplankton	0.1821	0.3563	0.2635
1	Medium Forage Fish	0.3427	0.5871	0.4240
1	Sciaenids	0.9052	0.7520	0.9249
2	Menhaden	0.3910	0.2996	0.4760
2	Anchovy	0.4258	0.4874	0.6796
2	Crustaceans	0.4965	0.4639	0.6678
2	Inverts	0.3404	0.5770	0.6676
2	Herrings	0.1681	0.5635	0.4816
2	Macrozooplankton	0.3017	0.4333	0.5063
2	Medium Forage Fish	0.4623	0.4836	0.6801
2	Sciaenids	0.1731	0.1880	0.2381
3	Menhaden	0.3968	0.1972	0.1755
3	Anchovy	0.4183	0.3430	0.3213
3	Crustaceans	0.3820	0.3195	0.2780
3	Inverts	0.3788	0.4477	0.6644
3	Herrings	0.0000	0.0674	0.3035
3	Macrozooplankton	0.2633	0.3170	0.5337
3	Medium Forage Fish	0.3381	0.4172	0.6339
3	Sciaenids	0.3665	0.1285	0.1068
4	Menhaden	0.6096	0.1629	0.1110
4	Anchovy	0.5065	0.3637	0.3325
4	Crustaceans	0.5601	0.3560	0.3090
4	Inverts	0.4608	0.4572	0.5456
4	Herrings	0.0000	0.0410	0.1767
4	Macrozooplankton	0.3067	0.3265	0.4149
4	Medium Forage Fish	0.4114	0.4267	0.5151
4	Sciaenids	0.5966	0.1373	0.0854

Table D.31. Seasonal spatial overlap values for striped bass.

Season	Prey	Age 1	Age 2	Age 3	Age 4	Age 5	Age 6	Age 7	Age 8	Age 9	Age 10	Age 11	Age 12	Age 13+
1	Menhaden	0.0000	0.0000	0.0000	0.0162	0.0000	0.0069	0.0528	0.1593	0.4259	0.6320	0.5773	0.4656	0.4241
1	Anchovy	0.4504	0.4504	0.5084	0.5340	0.5140	0.5140	0.5500	0.6725	0.7392	0.6680	0.7227	0.7326	0.7210
1	Crustaceans	0.3840	0.3840	0.4420	0.4675	0.4476	0.4476	0.4835	0.6061	0.7626	0.7550	0.7542	0.7560	0.7444
1	Inverts	0.1160	0.1160	0.1740	0.1996	0.1796	0.1796	0.2156	0.3381	0.3194	0.3117	0.3110	0.3128	0.3012
1	Herrings	0.1040	0.1040	0.1620	0.1876	0.1676	0.1676	0.1931	0.2091	0.1351	0.1274	0.1267	0.1285	0.1169
1	Macrozooplankton	0.1031	0.1031	0.1611	0.1835	0.1666	0.1667	0.2026	0.3251	0.2678	0.2601	0.2593	0.2611	0.2496
1	Medium Forage Fish	0.1422	0.1422	0.2002	0.2258	0.2058	0.2058	0.2418	0.3643	0.4675	0.4598	0.4591	0.4609	0.4493
1	Sciaenids	0.0976	0.0976	0.0976	0.1138	0.0976	0.1045	0.1504	0.2569	0.5235	0.7296	0.6749	0.5632	0.5217
2	Menhaden	0.6901	0.6901	0.5251	0.4473	0.3716	0.3035	0.3072	0.2578	0.3707	0.4219	0.3480	0.3176	0.3371
2	Anchovy	0.6000	0.6000	0.6568	0.6351	0.5594	0.4913	0.4922	0.4305	0.4772	0.5397	0.4276	0.3919	0.4114
2	Crustaceans	0.5622	0.5622	0.6032	0.6117	0.5360	0.4506	0.4401	0.3785	0.4252	0.4876	0.3755	0.3399	0.3593
2	Inverts	0.2082	0.2082	0.2869	0.4569	0.5314	0.6669	0.6466	0.7828	0.7346	0.8981	0.8413	0.7959	0.7781
2	Herrings	0.1945	0.1945	0.2732	0.4432	0.6270	0.7927	0.7757	0.8799	0.8279	0.7862	0.8586	0.8848	0.7930
2	Macrozooplankton	0.1671	0.1671	0.2458	0.4157	0.3877	0.5233	0.5029	0.6392	0.6149	0.8174	0.7706	0.6966	0.7571
2	Medium Forage Fish	0.2490	0.2490	0.3277	0.4791	0.4380	0.5735	0.5532	0.6794	0.6266	0.7951	0.7048	0.6594	0.6416
2	Sciaenids	0.6695	0.6695	0.4325	0.3357	0.2600	0.1919	0.1956	0.1462	0.2591	0.3093	0.2364	0.2117	0.2522
3	Menhaden	0.7783	0.7783	0.6347	0.4725	0.3655	0.2758	0.2707	0.2198	0.2628	0.2920	0.2218	0.2054	0.2211
3	Anchovy	0.6000	0.6000	0.6636	0.6183	0.4559	0.3188	0.3137	0.2628	0.3058	0.3350	0.2648	0.2484	0.2641
3	Crustaceans	0.5555	0.5555	0.6100	0.5949	0.4038	0.2667	0.2616	0.2107	0.2538	0.2829	0.2127	0.1964	0.2121
3	Inverts	0.2082	0.2082	0.3893	0.6619	0.6113	0.7169	0.6756	0.7202	0.7236	0.7719	0.7242	0.7036	0.6968
3	Herrings	0.0001	0.0001	0.1694	0.3111	0.2040	0.3666	0.3285	0.4800	0.3749	0.5615	0.5533	0.5049	0.5994
3	Macrozooplankton	0.1671	0.1671	0.3482	0.5771	0.4676	0.6015	0.5601	0.7066	0.6081	0.8388	0.7840	0.7149	0.7636
3	Medium Forage Fish	0.2804	0.2804	0.4615	0.7212	0.5726	0.6762	0.6349	0.6765	0.6829	0.7394	0.6785	0.6621	0.6643
3	Sciaenids	0.8413	0.8413	0.5809	0.4038	0.2968	0.2188	0.2137	0.1628	0.2058	0.2350	0.1648	0.1484	0.1641
4	Menhaden	0.4607	0.4607	0.4720	0.4916	0.4857	0.4752	0.4785	0.4310	0.6106	0.7224	0.6433	0.5938	0.6866
4	Anchovy	0.6000	0.6000	0.6113	0.6762	0.6673	0.6912	0.6895	0.6525	0.7811	0.8607	0.8013	0.7394	0.7935
4	Crustaceans	0.5622	0.5622	0.5736	0.6023	0.5933	0.6121	0.6253	0.6291	0.7140	0.8582	0.7492	0.6873	0.6750
4	Inverts	0.2082	0.2082	0.2195	0.2844	0.4264	0.4556	0.4637	0.5235	0.6320	0.6125	0.6975	0.6579	0.6499
4	Herrings	0.0001	0.0001	0.0097	0.0222	0.0191	0.0464	0.0413	0.0733	0.0465	0.0660	0.0816	0.0787	0.0948
4	Macrozooplankton	0.1671	0.1671	0.1784	0.2433	0.2828	0.3120	0.3200	0.3798	0.4860	0.5055	0.5212	0.5182	0.5126
4	Medium Forage Fish	0.2804	0.2804	0.2917	0.3566	0.4269	0.4561	0.4642	0.5240	0.6030	0.6587	0.6481	0.6172	0.6124
4	Sciaenids	0.3526	0.3526	0.3527	0.3587	0.3527	0.3546	0.3678	0.3956	0.5309	0.6967	0.6176	0.5432	0.5536

Table D.32. Single-species feeding parameter input for the biomass predator bluefish by size class. The proportion of biomass attributed to each size class is also presented.

Parameter\Size Class	10-30cm	30-60cm	60-90cm
Evacuation α	0.004	0.004	0.004
Evacuation β	0.115	0.115	0.115
Size Preference α	8.65	8.65	8
Size Preference β	25	25	25
Proportion of Biomass	0.025	0.265	0.71

Table D.33. Annual temperatures by season used in base run configuration in the MSVPA.

Year	Season 1	Season 2	Season 3	Season 4
1982	12.04	15.6	21.69	13.77
1983	12.04	15.87	21.65	13.73
1984	12.04	15.87	21.78	13.75
1985	12.1	16.13	22.3	14
1986	12.12	16.34	22.25	14.36
1987	12.2	15.87	22.59	13.48
1988	12.02	16.19	21.61	13.83
1989	12.39	16.28	22.42	13.4
1990	12.56	16.08	22.56	14.9
1991	12.83	17.53	22.73	14.16
1992	12.47	14.36	21.25	13.65
1993	12.22	16.32	22.24	13.39
1994	12.1	15.62	21.38	14.62
1995	12.44	15.9	22.57	13.66
1996	11.58	15.23	21.64	13.26
1997	12.54	14.53	21.85	13.73
1998	12.91	15.88	22.54	14.73
1999	12.47	15.67	22.63	14.71
2000	12.5	15.57	21.78	13.89
2001	12.19	15.98	22.31	14.82
2002	12.95	16.2	23.19	14.14

Table D.34. Base run configuration for ‘Other Prey’ minimum and maximum length and size (α and β) parameters.

Other Prey	Min Length (cm)	Max Length (cm)	α	β
Bay Anchovy	2	11	12.45	9.69
Benthic Crust	1	21	6.54	3.35
Benthic Invert	1	6	3.29	3.32
Clupeids	7	39	4.87	3.46
Macrozoopl.	1	4	4.74	2.73
Med. For. Fish	1	27	1.15	2.52
Sciaenids	9	24	13.1	5.84

Table D.35. Quantitative prey preference rankings for weakfish by age as used in the base run configuration of the MSVPA-X model.

	Age-0	Age-1	Age-2	Age-3	Age-4	Age-5	Age-6
Striped Bass	0	0	0	0	0	0	0
Weakfish	0	0	0	0	0	0	0
Menhaden	4	1	1	3	3	1	3
Bay Anchovy	3	2	4	6	6	6	5
Benthic Crust.	0	6	5	5	4	4	4
Benthic Invert.	2	7	6	8	8	8	8
Clupeids	0	0	0	2	2	2	2
Macrozoopl.	1	5	7	7	7	7	7
Medium Forage	0	4	3	4	5	5	6
Sciaenids	0	3	2	1	1	3	1

Table D.36. Spatial overlap indices for weakfish by age as used in the base run configuration of the MSVPA-X model.

	Age-0	Age-1	Age-2	Age-3	Age-4	Age-5	Age-6
Striped Bass	0	0	0	0	0	0	0
Weakfish	0	0	0	0	0	0	0
Menhaden	0.9282	0.9282	0.9631	0.9725	0.9733	0.8853	0.9091
Bay Anchovy	0.3718	0.3718	0.3369	0.3275	0.3267	0.4147	0.3909
Benthic Crust.	0.4617	0.4617	0.4267	0.4173	0.4165	0.4781	0.448
Benthic Invert.	0.2808	0.2808	0.2515	0.2421	0.2413	0.3293	0.3055
Clupeids	0.0965	0.0965	0.0792	0.0698	0.069	0.157	0.1332
Macrozoopl.	0.2291	0.2291	0.2128	0.2034	0.2027	0.2906	0.2669
Medium Forage	0.4083	0.4083	0.3734	0.364	0.3632	0.4512	0.4274
Scianieds	0.9742	0.9742	0.937	0.9237	0.9208	0.9296	0.9171

Table D.37. Predator evacuation and prey size preference parameter values for the base run.

Species (ages)	Evacuation α	Evacuation β	Size Preference α	Size Preference β
Striped Bass (0-4)	0.004	0.115	2.98	11.244
Striped Bass (5-9)	0.004	0.115	9.1	35.2
Striped Bass (10-13+)	0.004	0.115	13.9	51.2
Weakfish	0.004	0.115	10.1	25.5
Bluefish	0.004	0.115	10.1	25.5

FIGURES

Figure D.1. Predator consumption related to food availability.

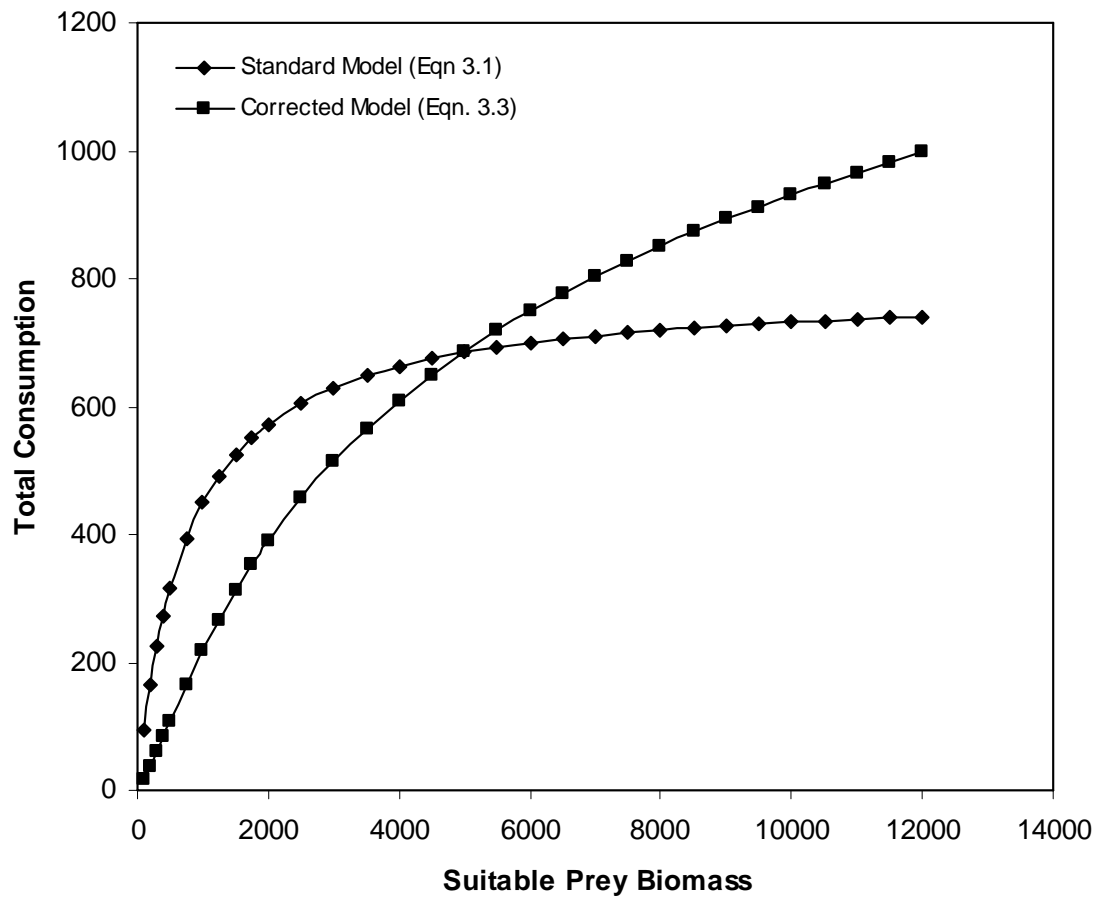


Figure D.2. Predator mortality rate related to food availability.

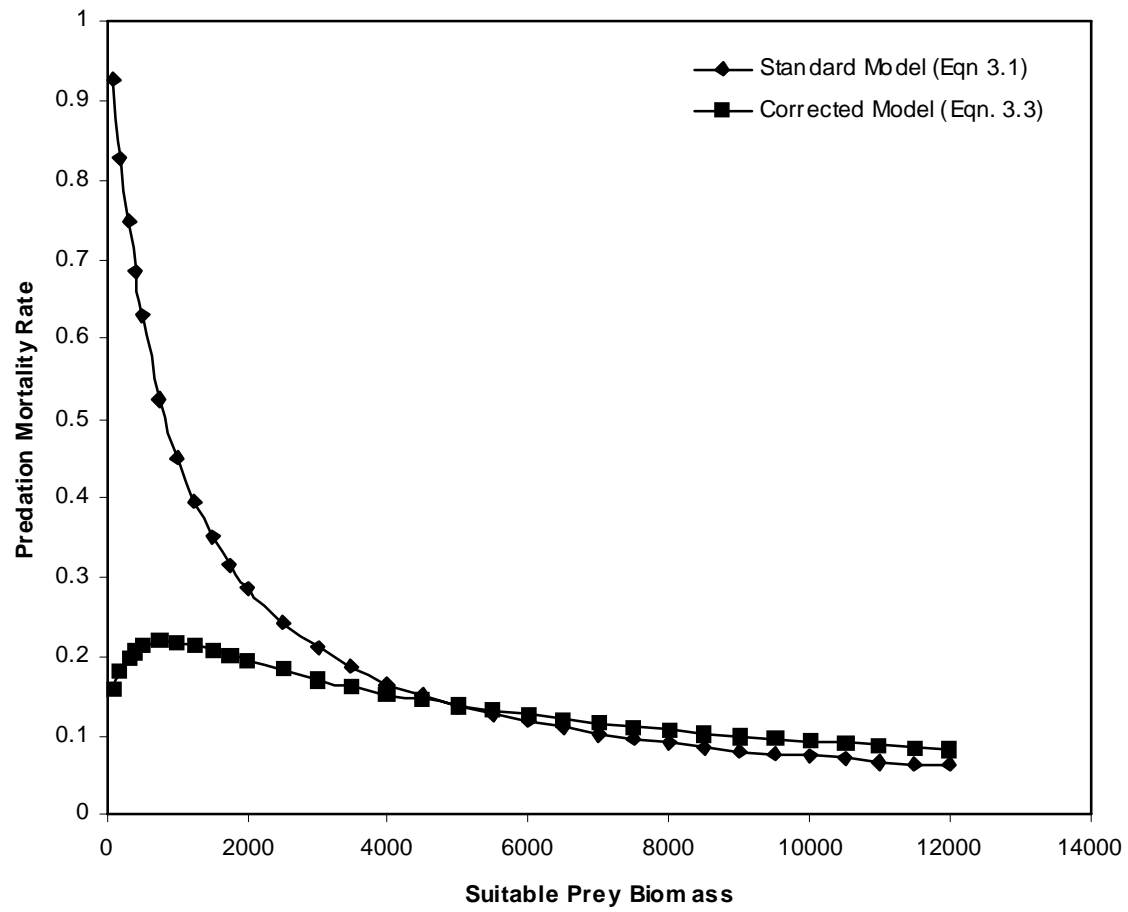


Figure D.3. Prey size selection curves.

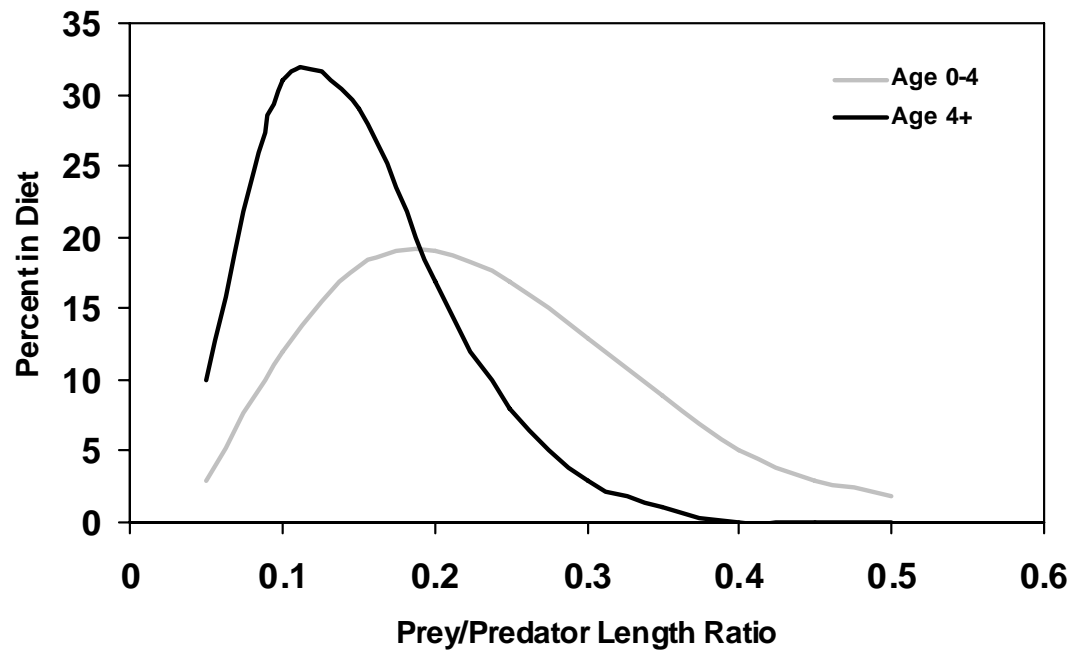


Figure D.4. MSVPA-X Implementation flow chart.

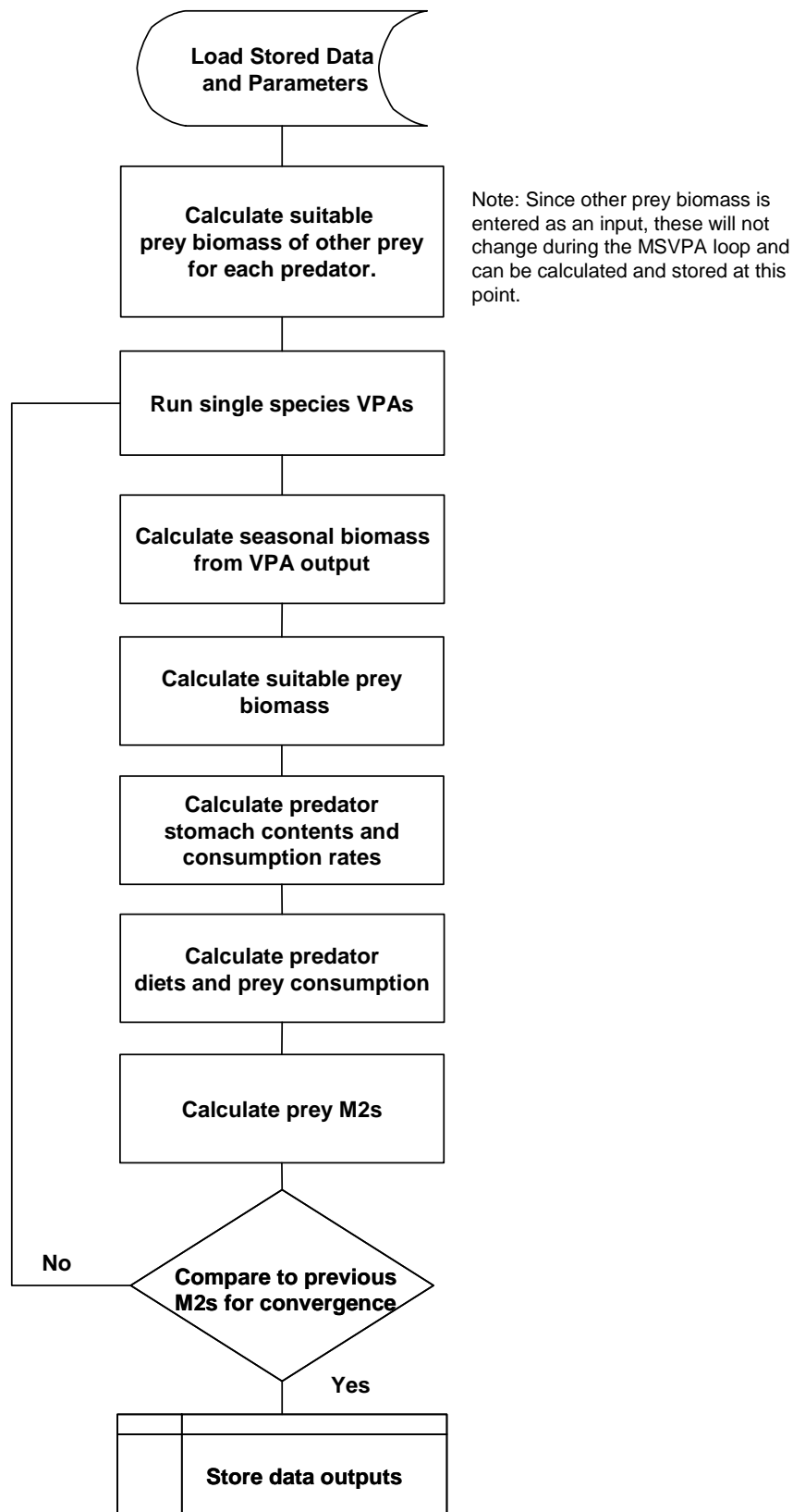


Figure D.5. Forecast model implementation flow chart.

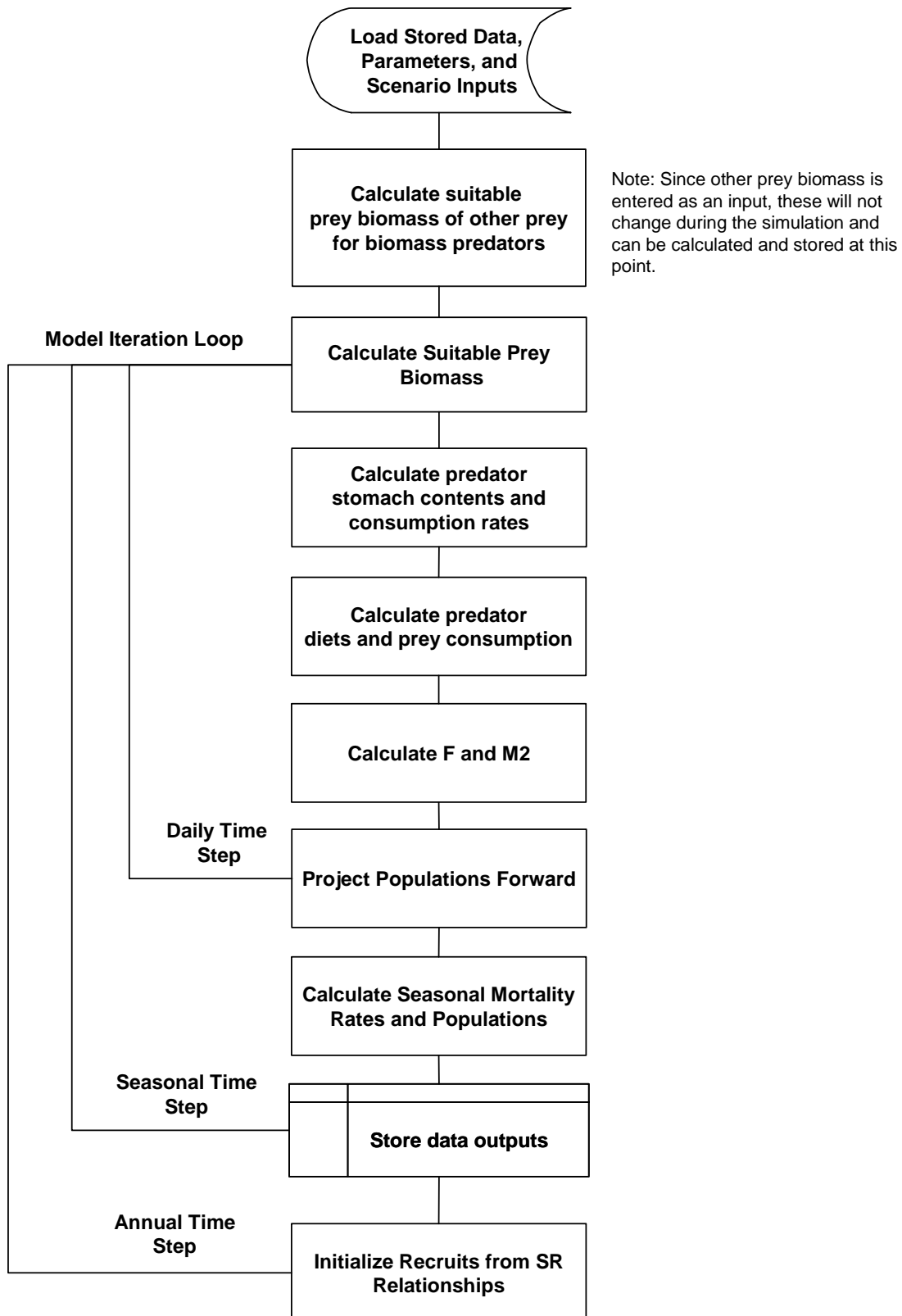


Figure D.6. Estimated average fishing mortality rate at age during 2000-2002 for Atlantic menhaden in evaluation runs assessing sensitivity to the number of age classes used to calculate shrinkage means.

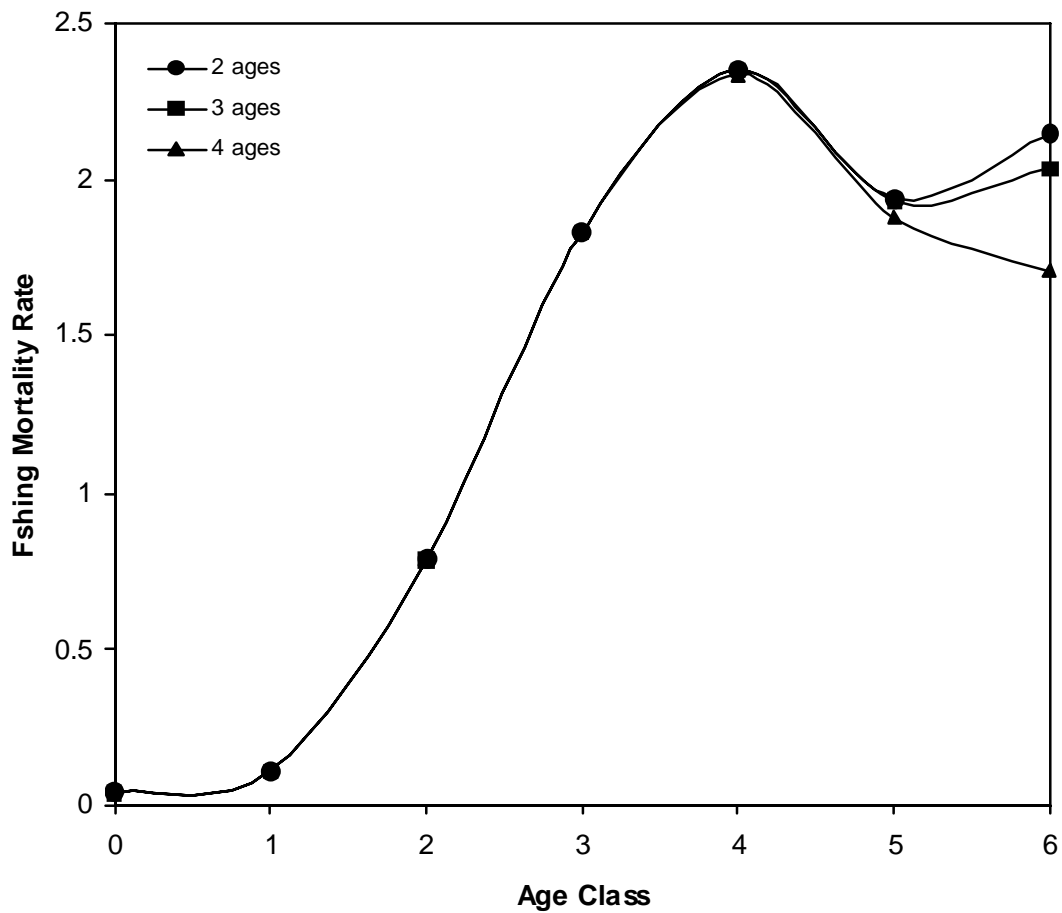


Figure D.7. Average fishery mortality rate on age classes 2+ menhaden estimated by the forward projection model and evaluation runs using Extended Survivors Analysis (XSA).

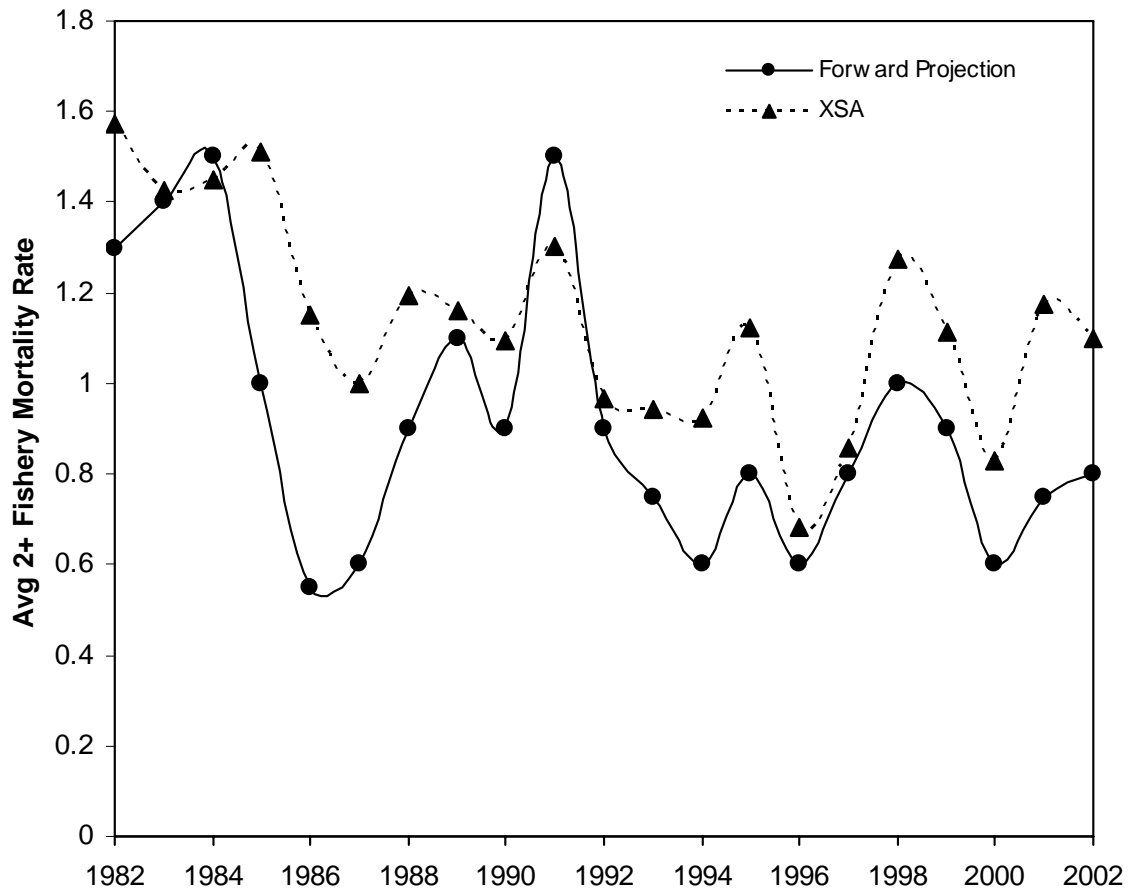


Figure D.8. Estimated abundance of (a) age-0, (b) age-1, and (c) age-3+ Atlantic menhaden in evaluation runs of the forward projection model and XSA.

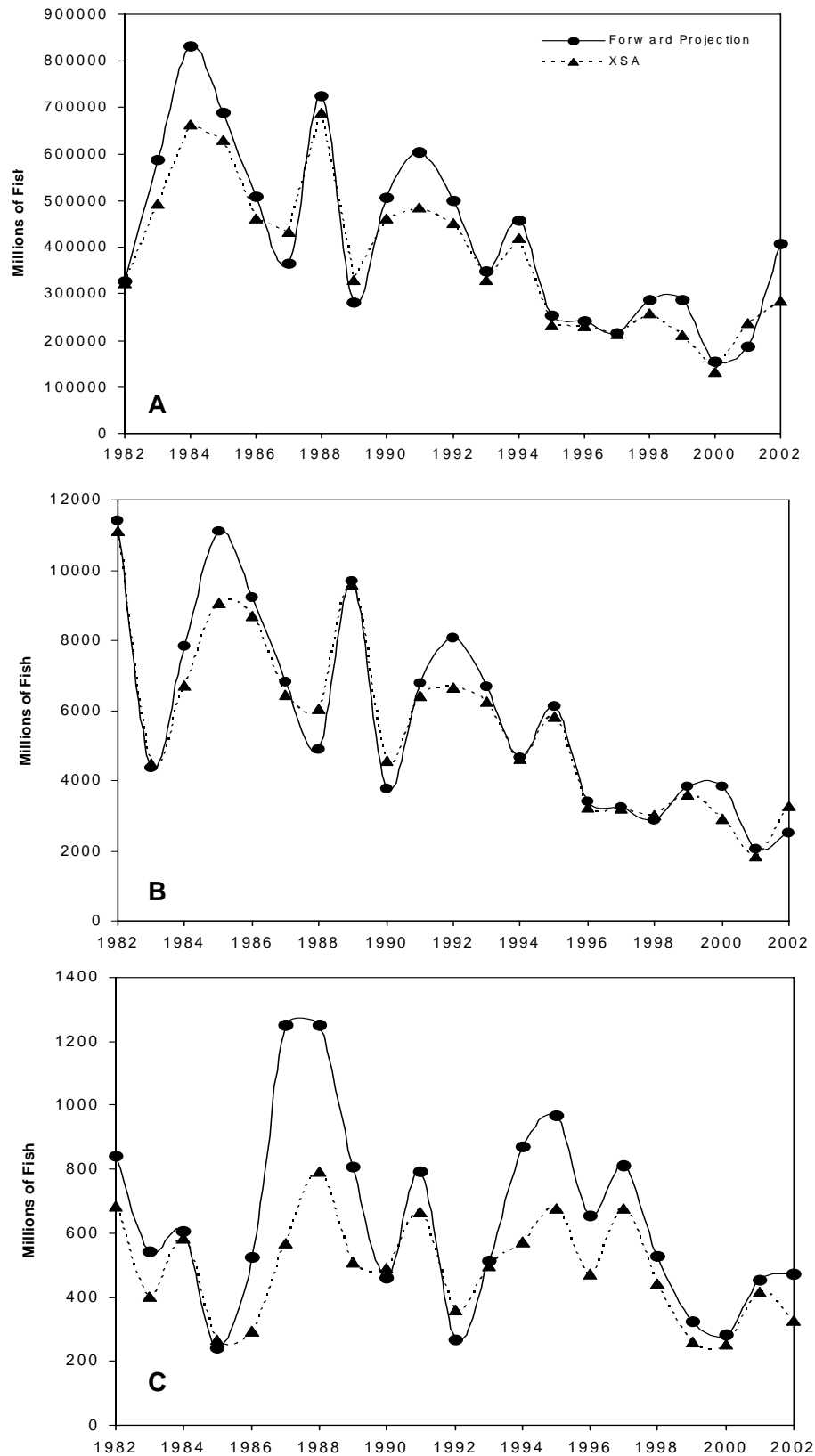


Figure D.9. Average fishery mortality rates for ages (A) 8-11 and (B) 3-8 for striped bass estimated from XSA evaluation runs. The ADAPT time series represents average F from the striped bass stock assessment (ASMFC, 2003).

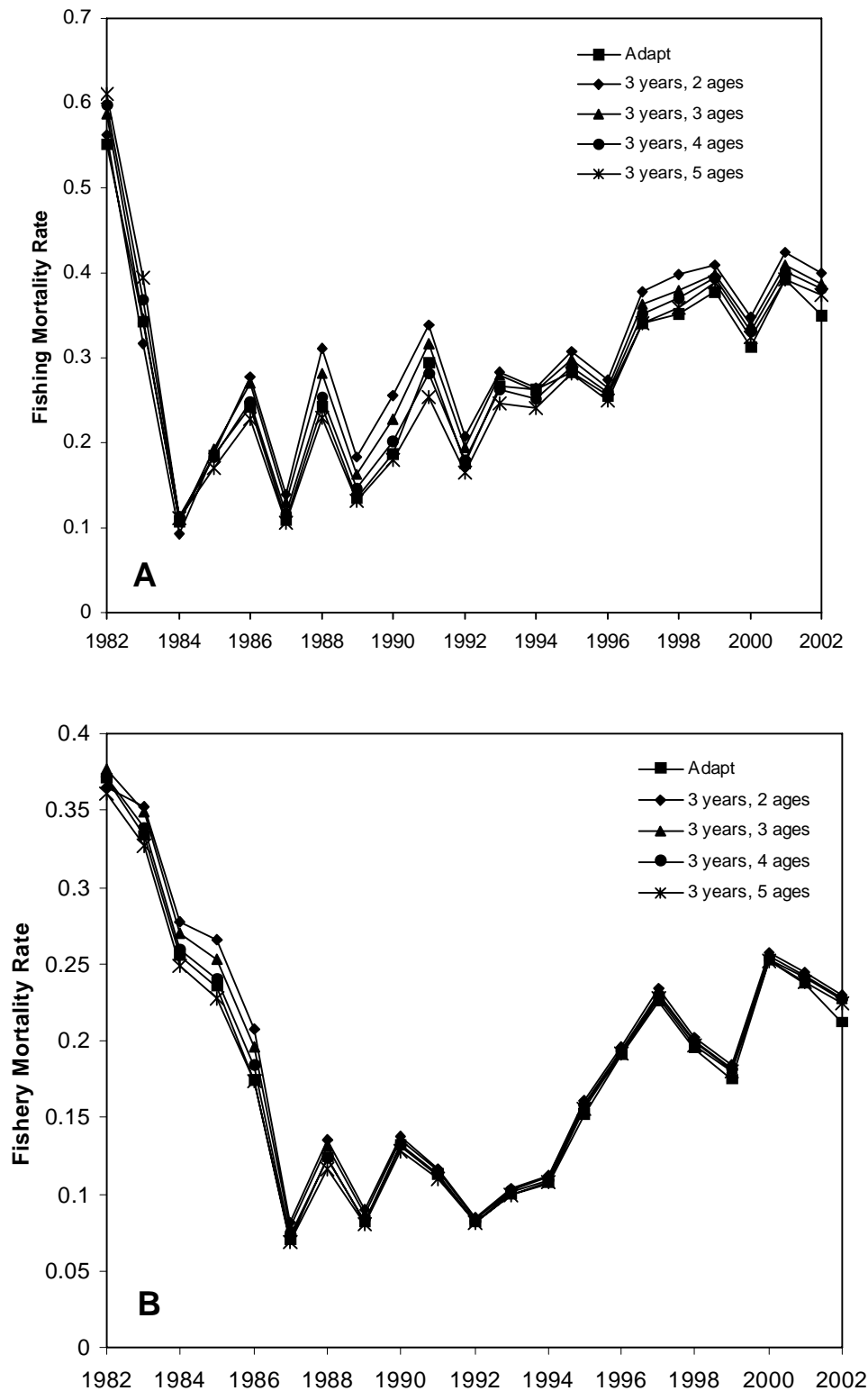


Figure D.10. Average fishery mortality rates during 2000-2002 by age class for the XSA evaluation run. The ADAPT time series represents output from the striped bass stock assessment (ASMFC, 2003).

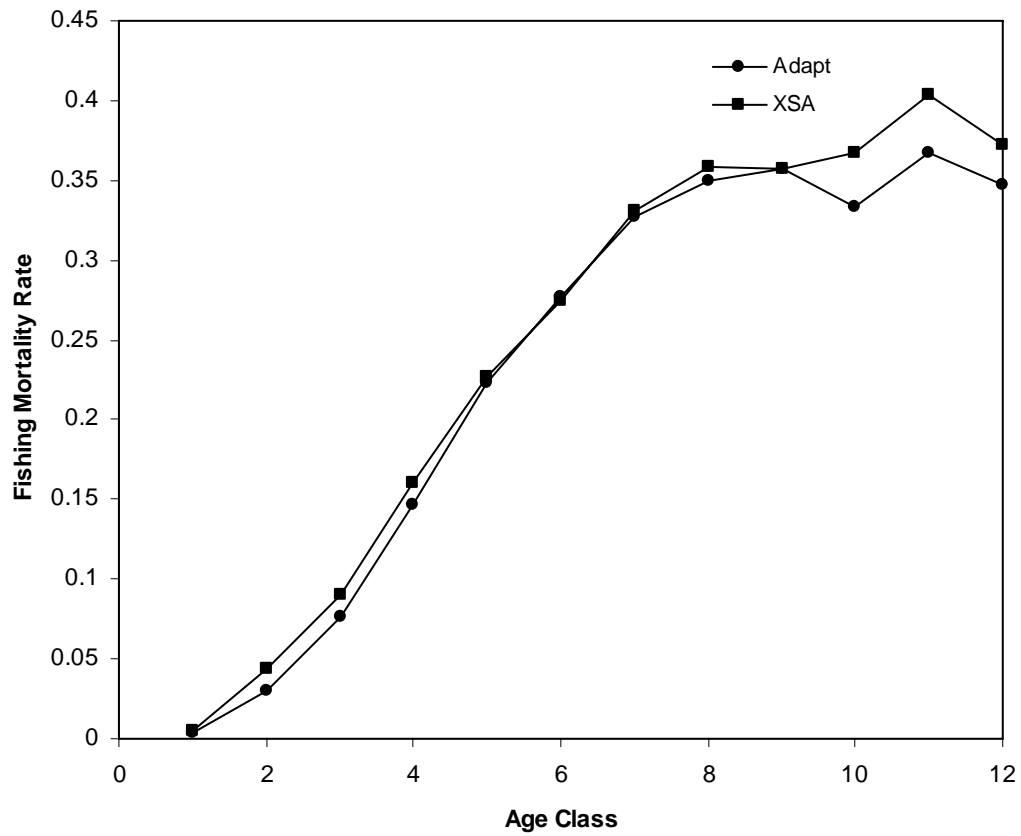


Figure D.11. Total abundance of striped bass age class 1 (A), ages 3-8 (B), and ages 8-11 (C) estimates from XSA evaluation runs. The ADAPT time series represents output from the striped bass stock assessment (ASMFC, 2003).

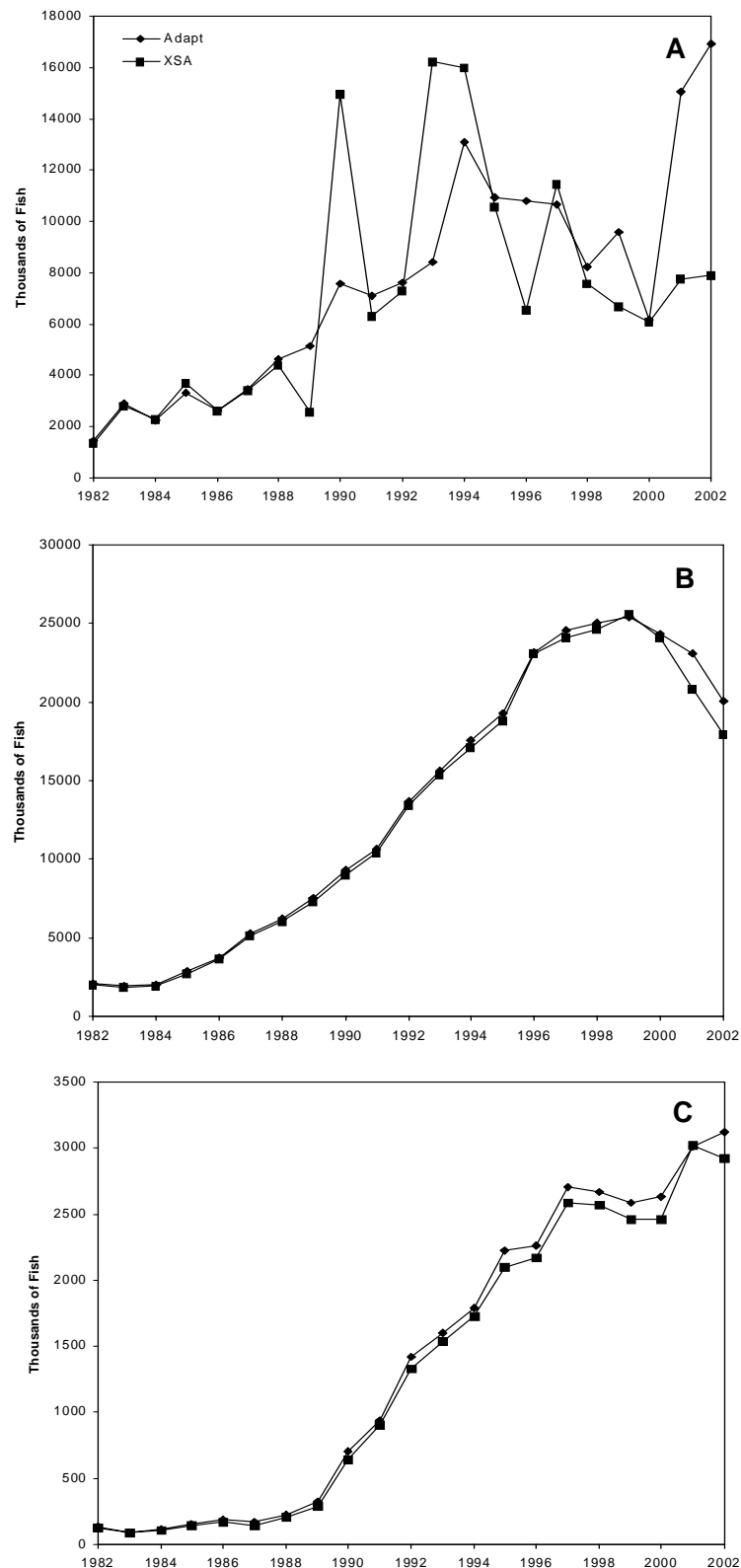


Figure D.12. Average age 4 and 5 fishing mortality rates for weakfish estimated by evaluation runs of the extended survivors analysis. Results from the ADAPT VPA assessment for weakfish (Kahn, 2002a) and an integrated catch at age (ICA) analysis are shown.

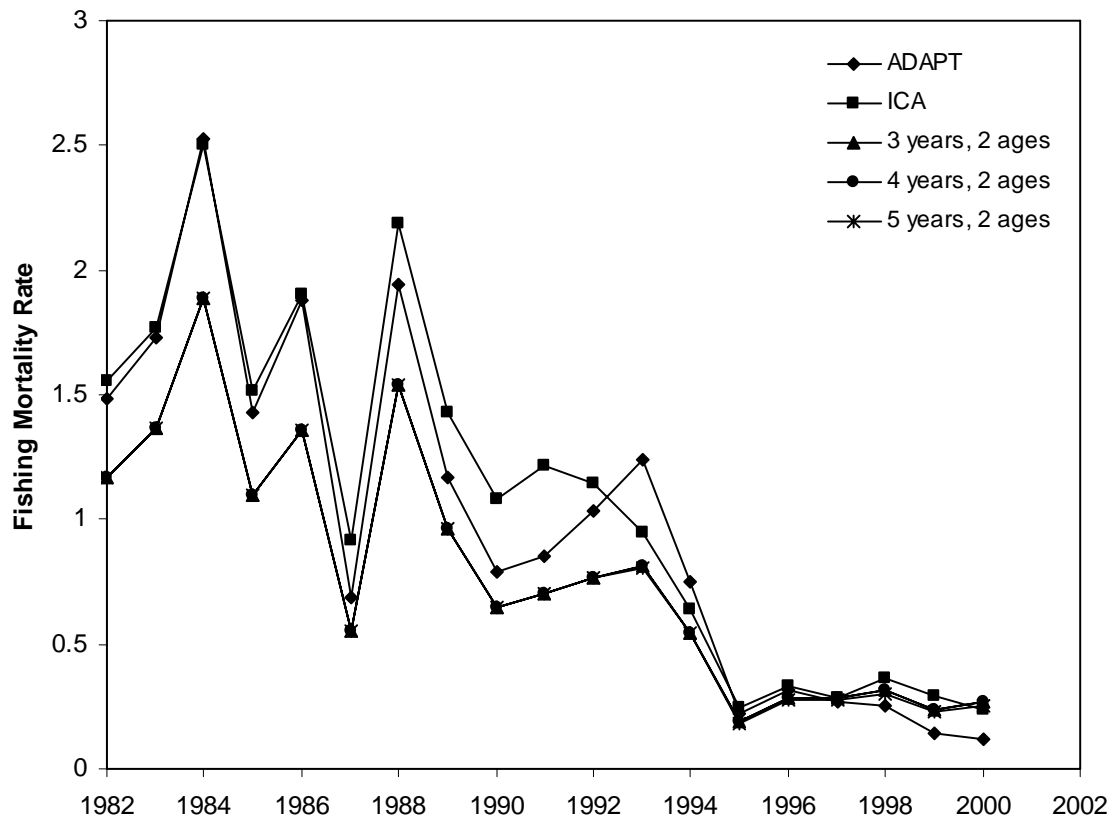


Figure D.13. Average fishing mortality rates by age class during 1998-2000 for weakfish estimated by evaluation runs of the extended survivors analysis. Results from the ADAPT VPA assessment for weakfish (Kahn, 2002a) and an integrated catch-at-age (ICA) analysis are shown.

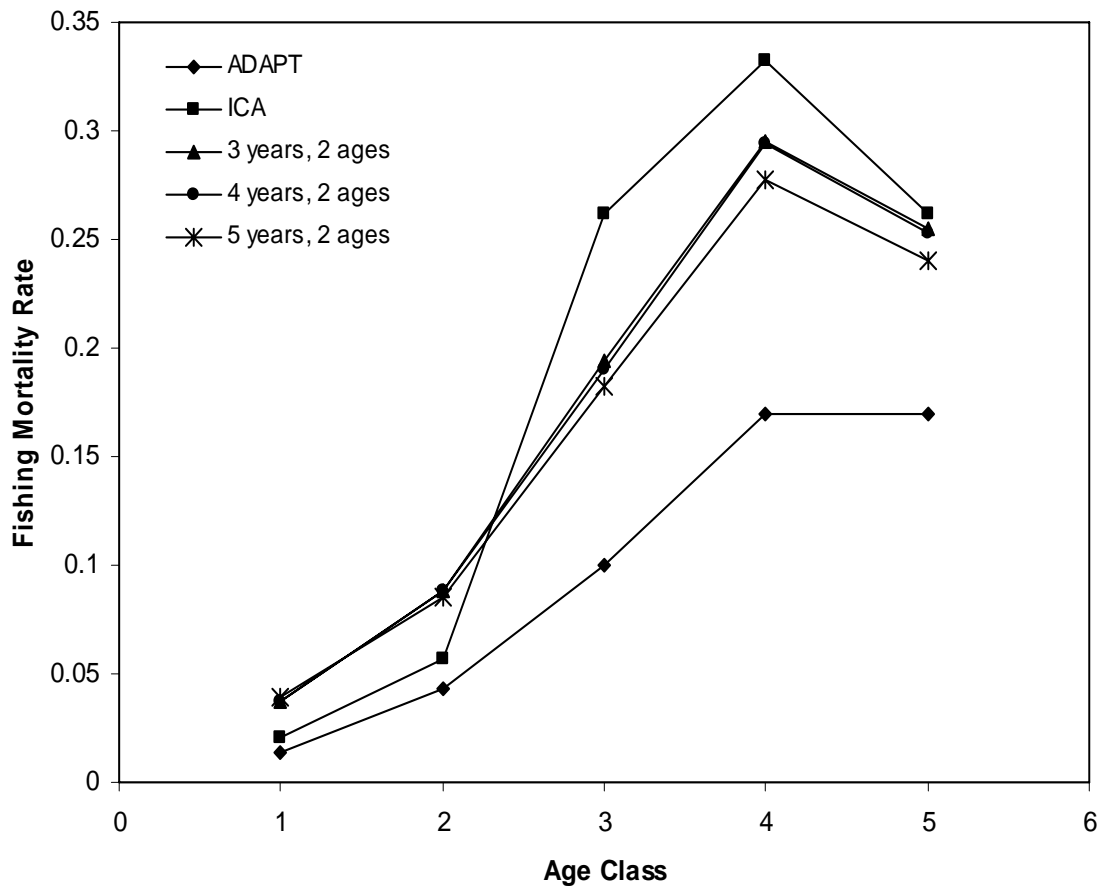


Figure D.14. Abundance of (A) ages 4-6+ and (B) ages 1-3 weakfish as estimated by XSA, ADAPT and ICA.

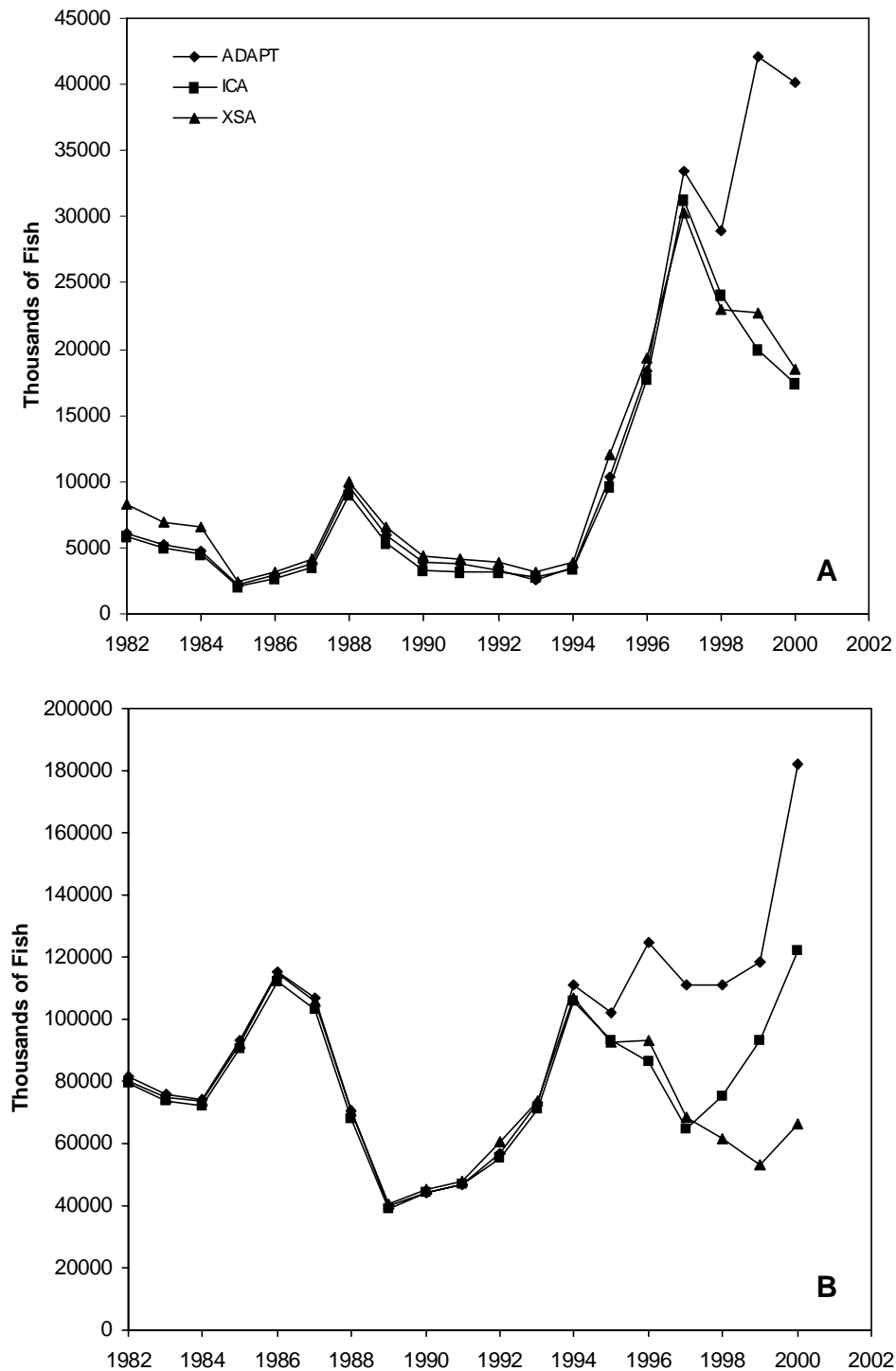


Figure D.15. Total biomass (000 mt) of the bluefish stock from 1982-2002 estimated by the ASPIC biomass-dynamic model (Lee, 2003).

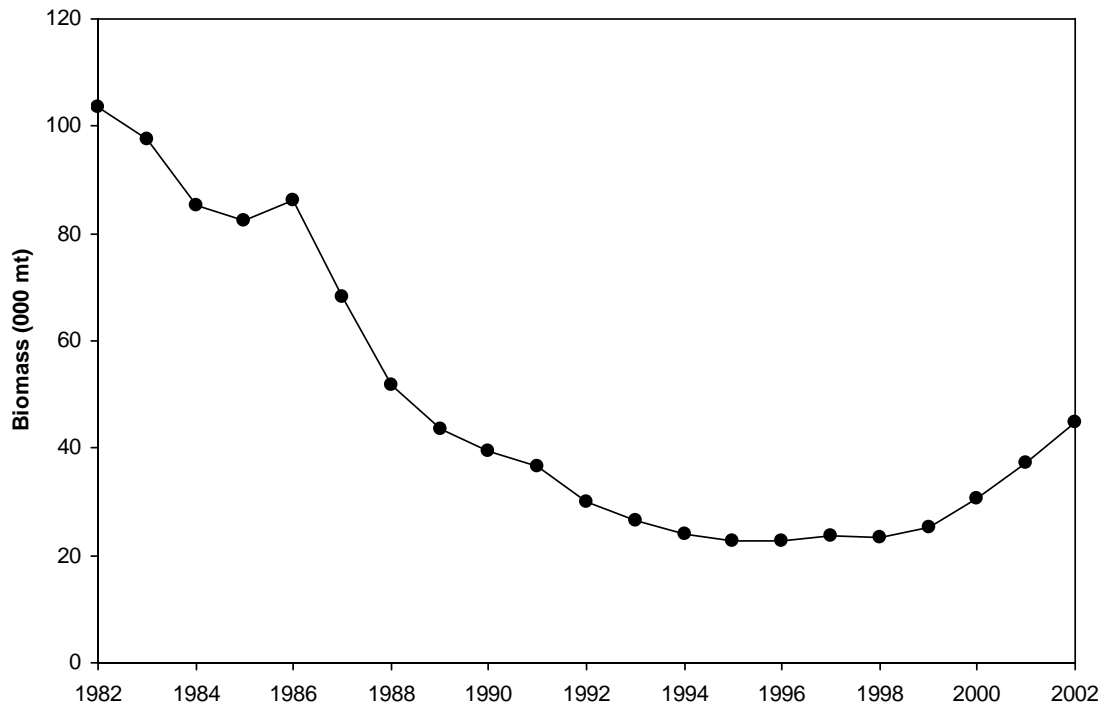


Figure D.16. Assumed biomass size distribution of the benthic invertebrate prey category.

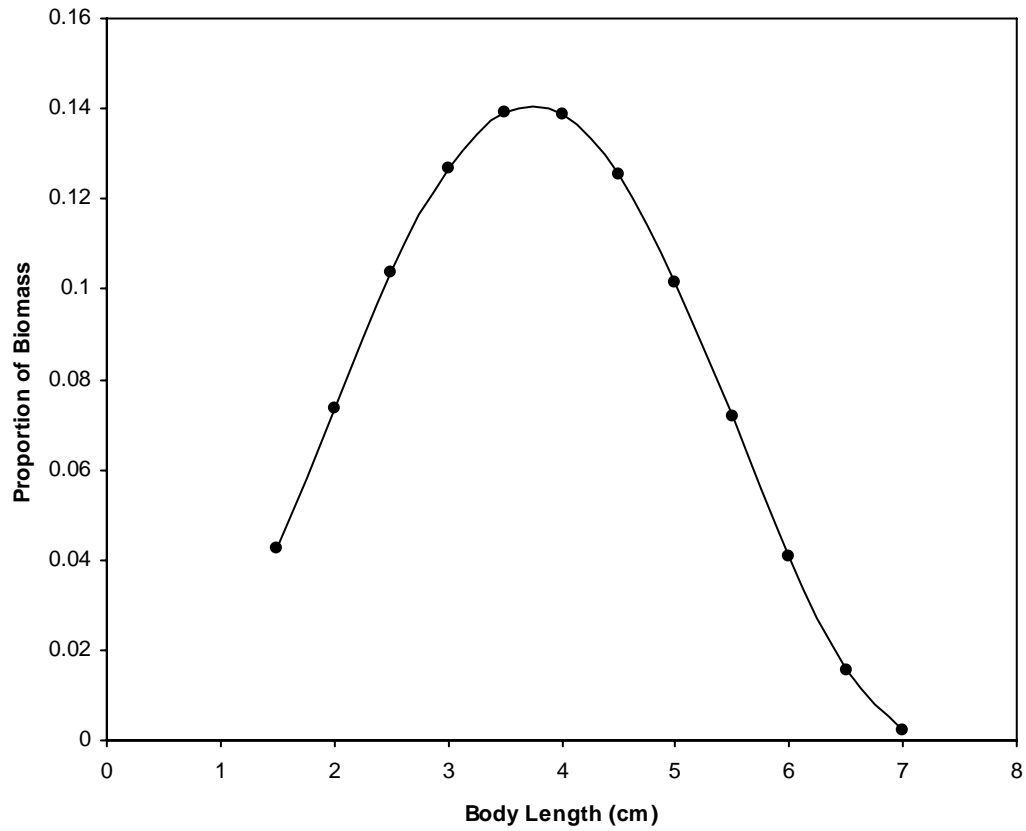


Figure D.17. Assumed biomass size distribution of the macrozooplankton prey category.

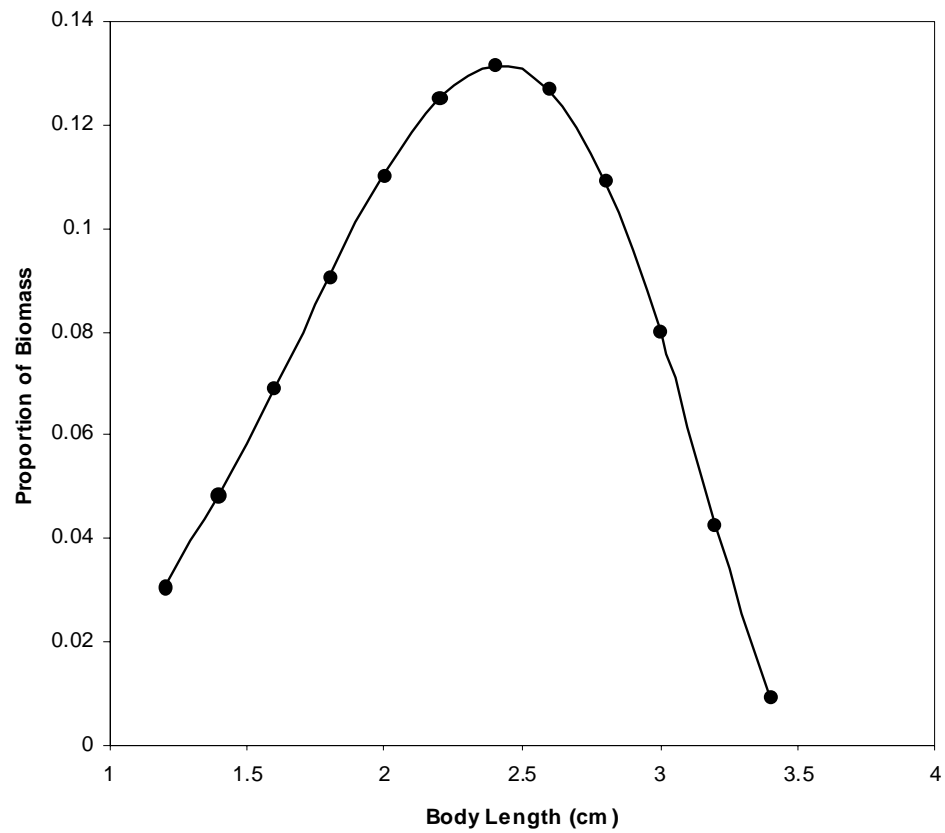


Figure D.18. Biomass size distribution of the benthic crustacean prey category.

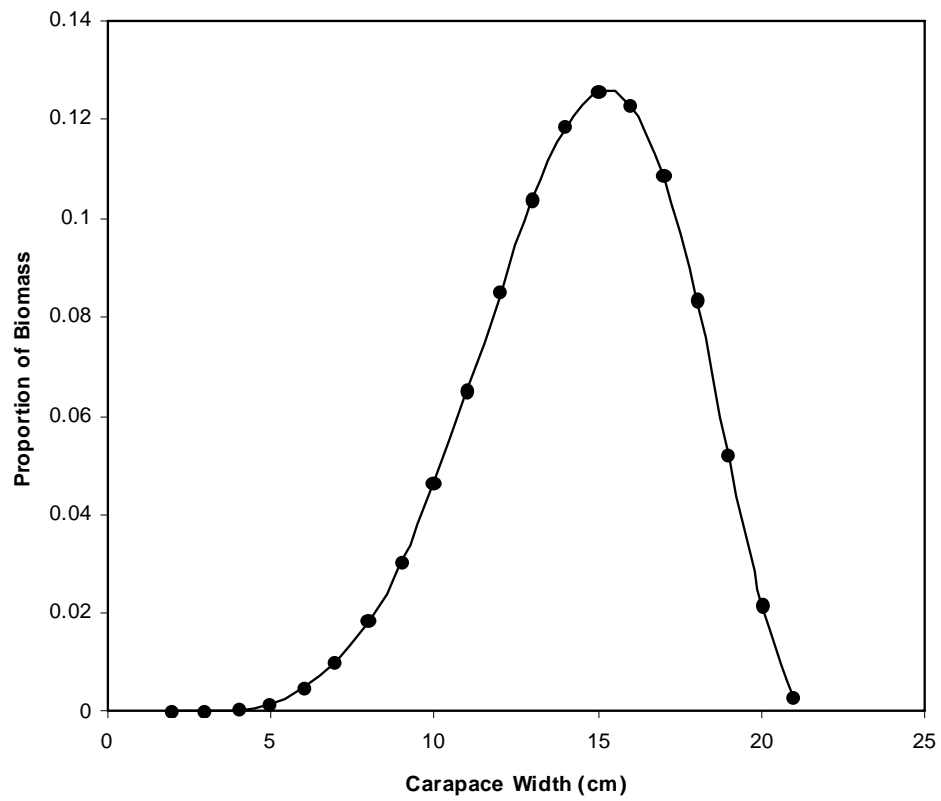


Figure D.19. Seasonal bay anchovy biomass (mt) estimates for the Chesapeake Bay (Rilling and Houde, 1999) and the New Jersey coast.

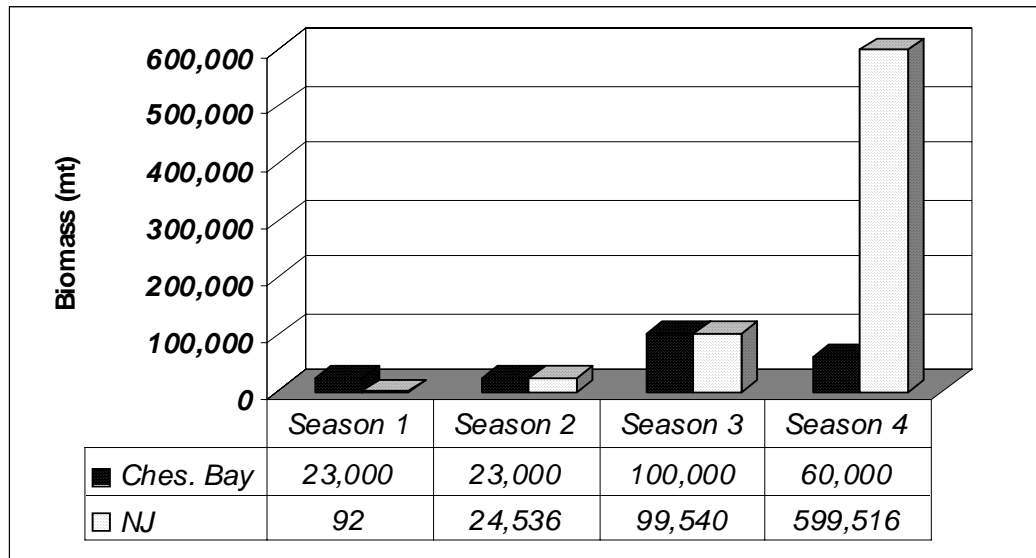


Figure D.20. Annual z-transformed (+2) CPUE indices for the Chesapeake Bay region.

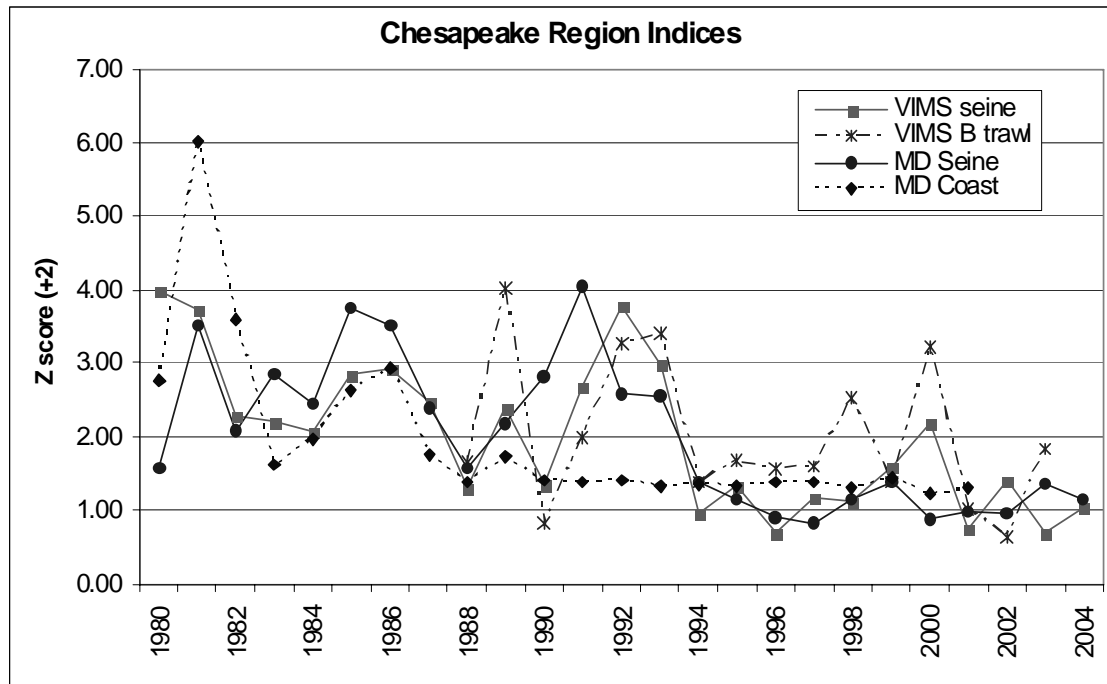


Figure D.21. Annual z-transformed (+2) CPUE indices for the Delaware Bay region.

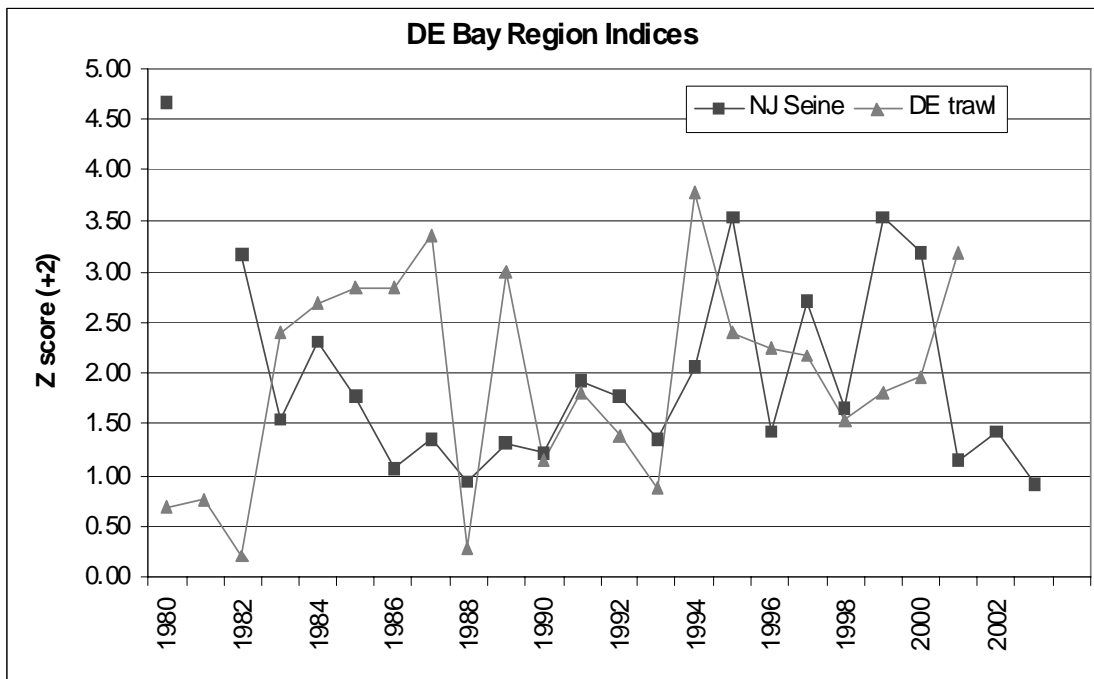


Figure D.22. Combined weighted Chesapeake Bay index, Delaware Bay index and a combined (Chesapeake and Delaware) *Estuary* index.

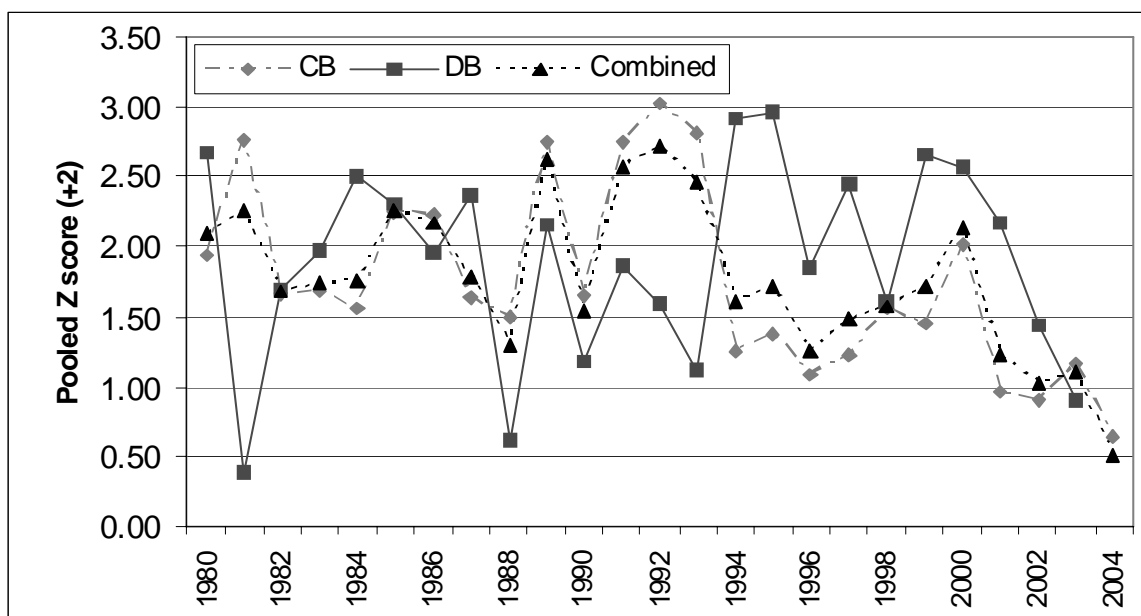


Figure D.23. Annual z-transformed (+3) CPUE indices for the NJ Ocean Trawl, SEAMAP survey, and a combined *Coastal* index.

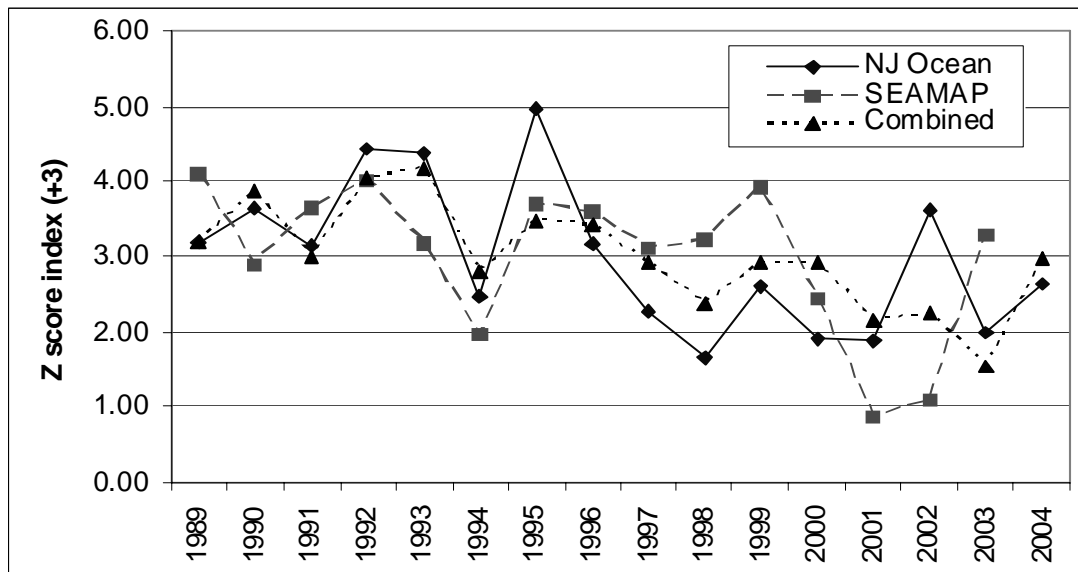


Figure D.24. Diet composition of (A) age-0, (B) age 1-2, and (C) age 3-5 striped bass in the Chesapeake Bay from Hartman & Brandt, 1995a.

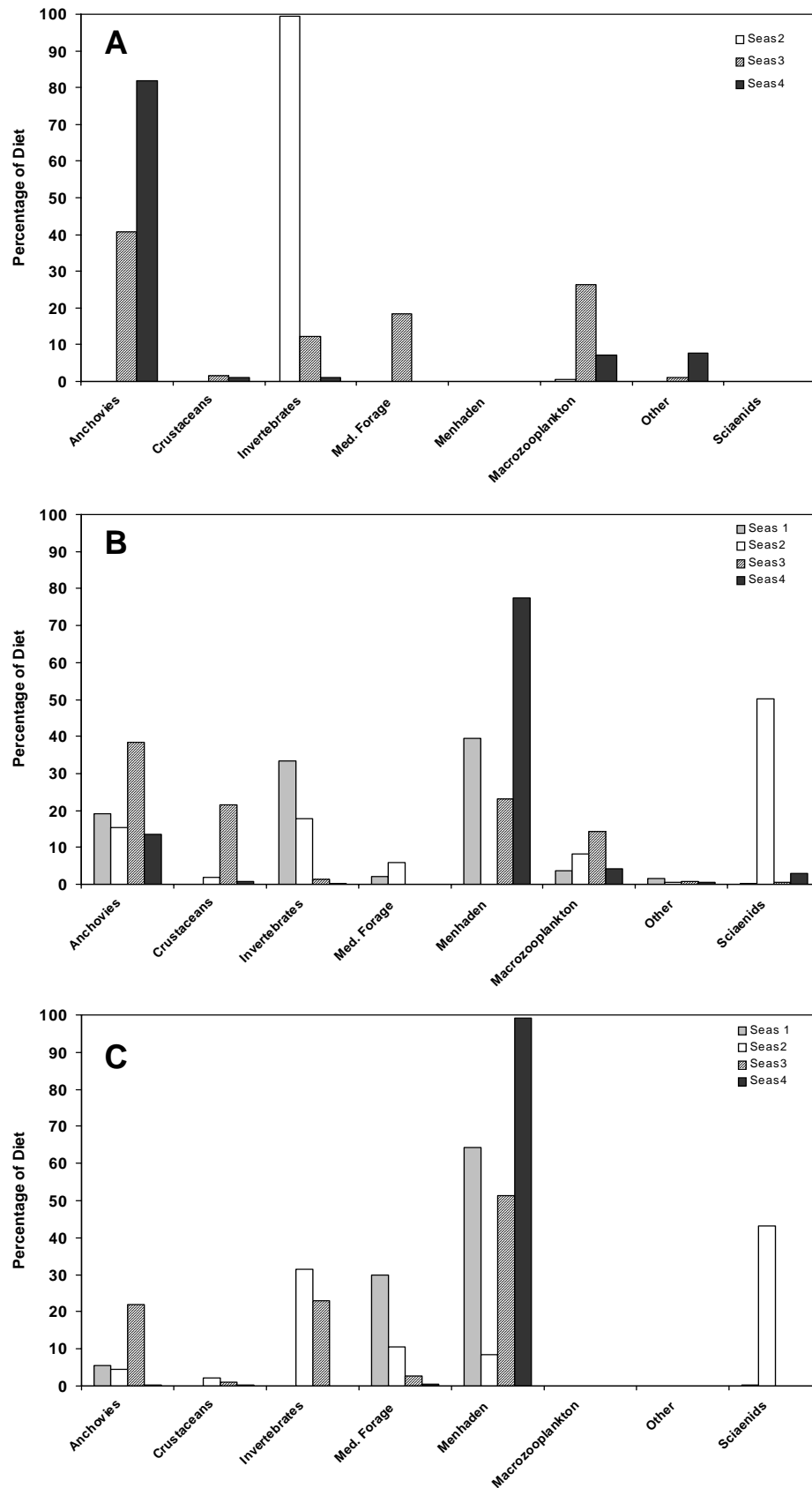


Figure D.25. Diet composition of (A) ages 5-6 and (B) ages 8+ striped bass in the Chesapeake Bay (Walter and Austin 2003).

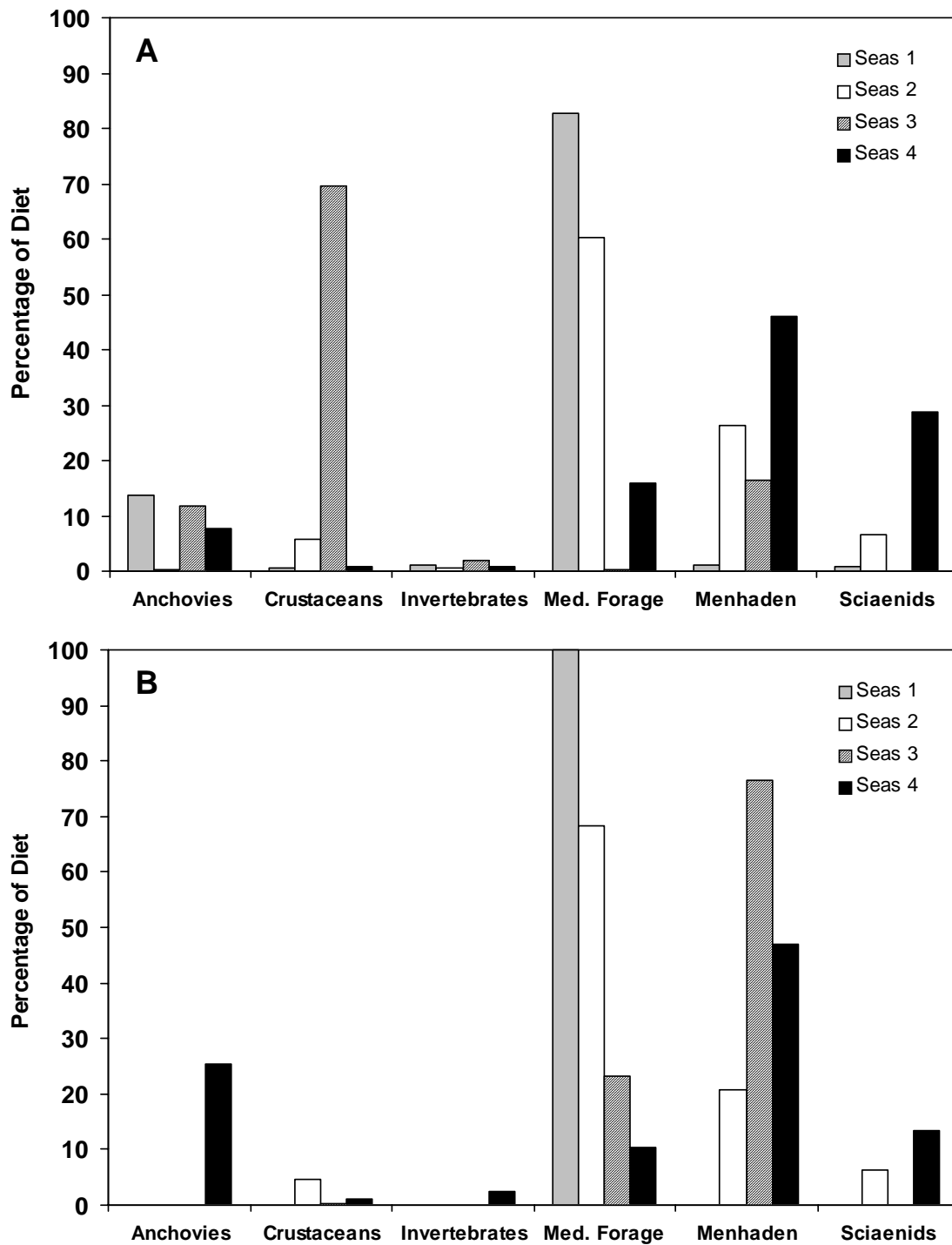


Figure D.26. Seasonal proportion of biomass in each prey category in the Chesapeake Bay region.

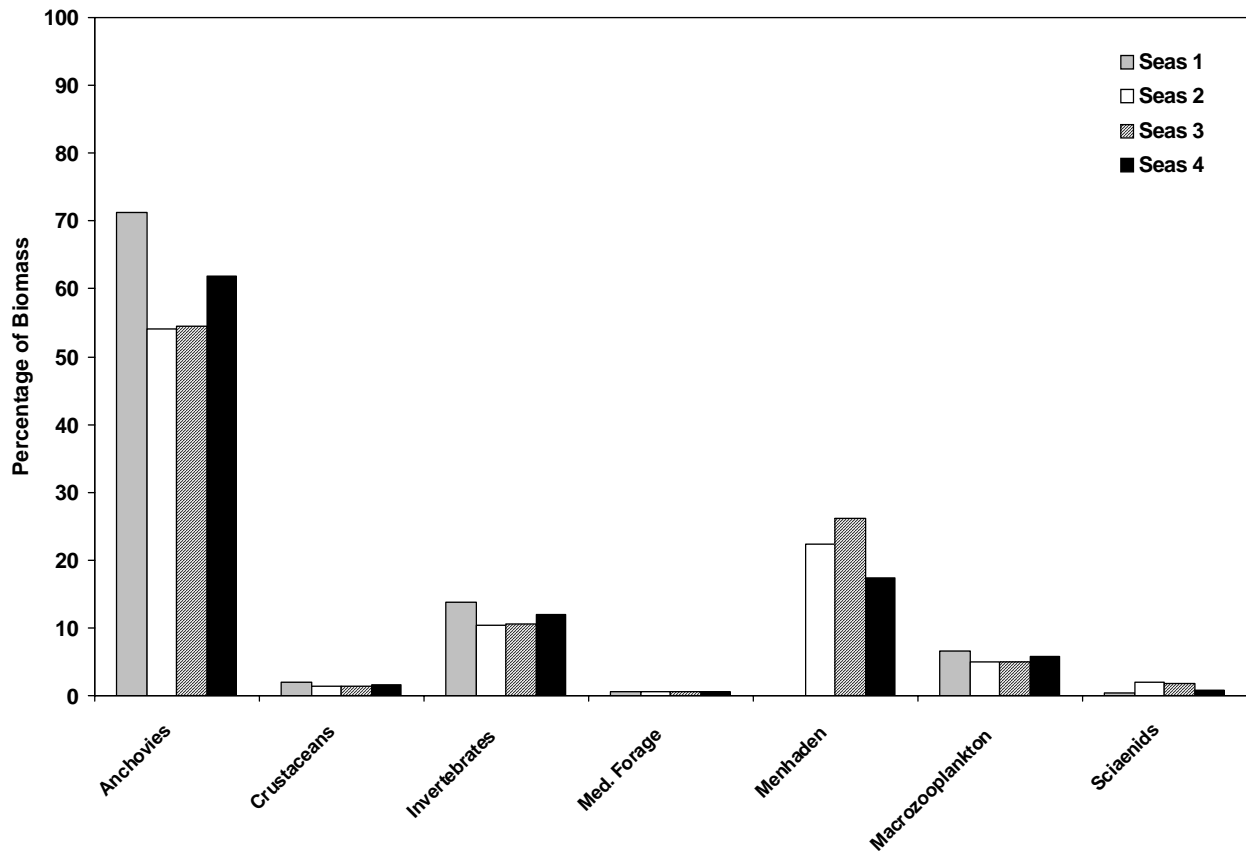


Figure D.27. Five regional strata were defined from North Carolina to the Gulf of Maine.

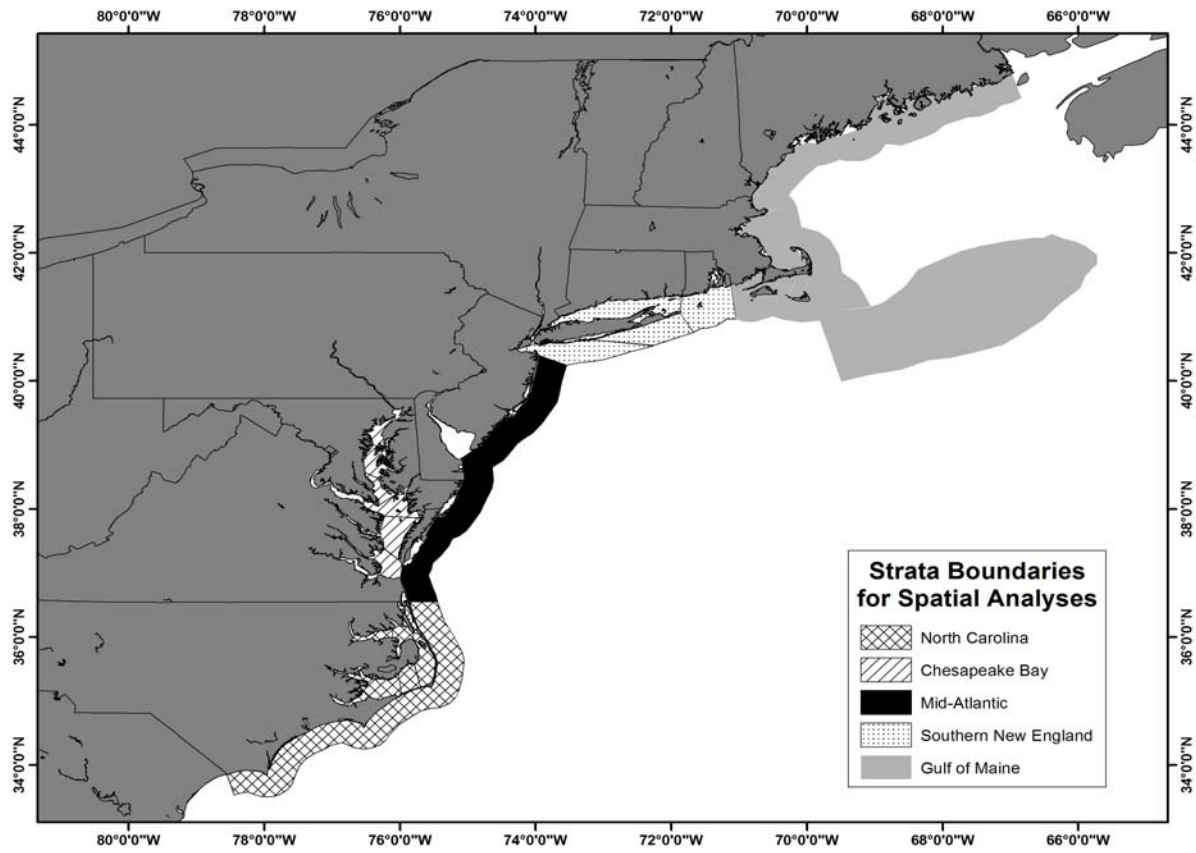
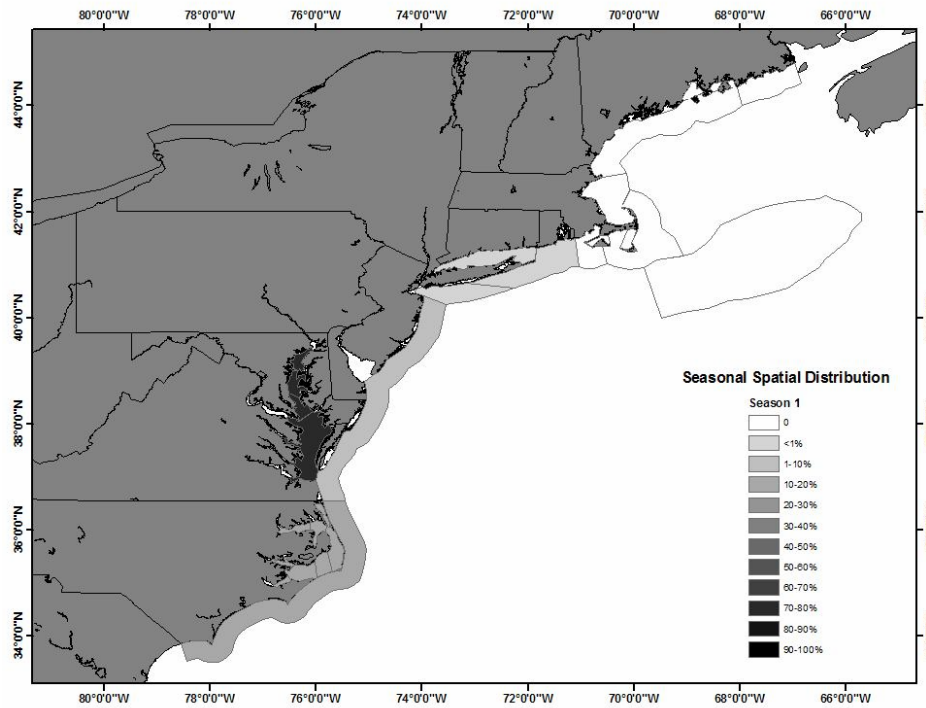


Figure D.28. Seasonal spatial distribution of striped bass based on landings data: a. Season 1; b. Season 2; c. Season 3; and d. Season 4.

a)



b)

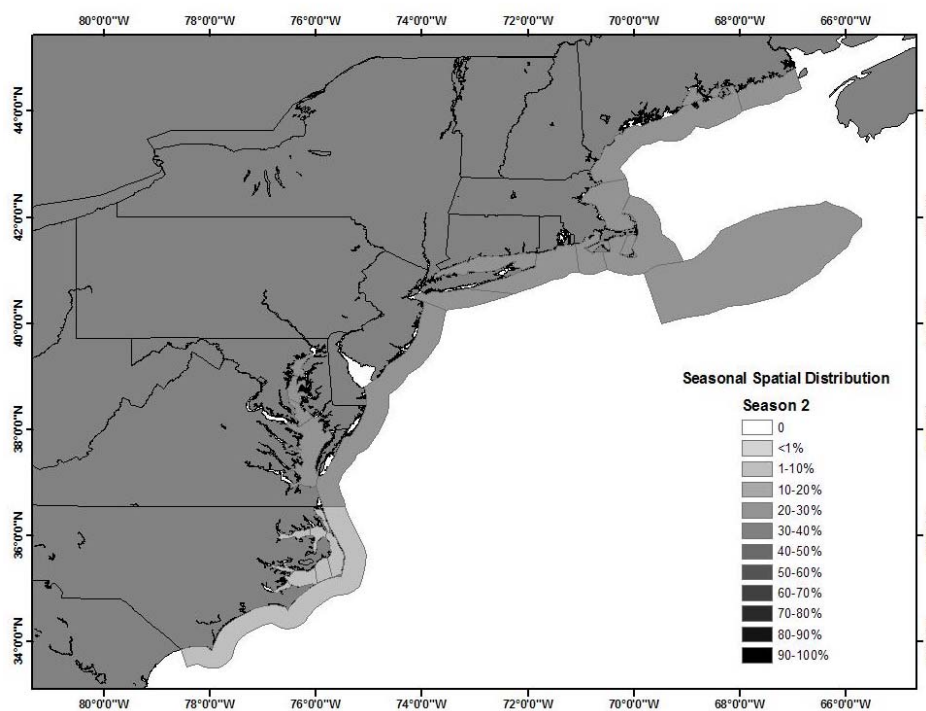
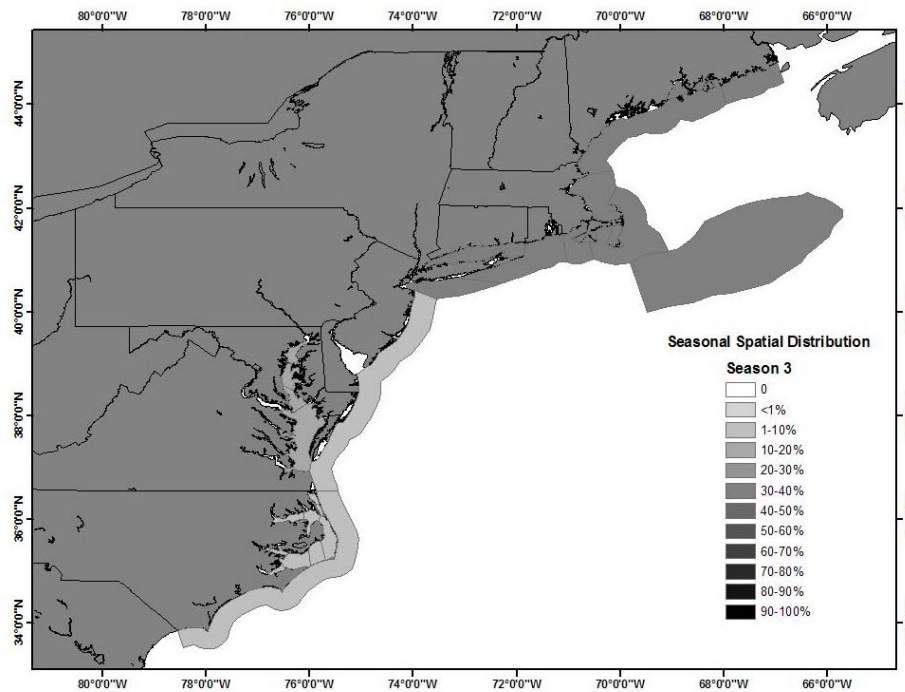


Figure D.28 (cont'd). Seasonal spatial distribution of striped bass based on landings data: a. Season 1; b. Season 2; c. Season 3; and d. Season 4.

c)



d)

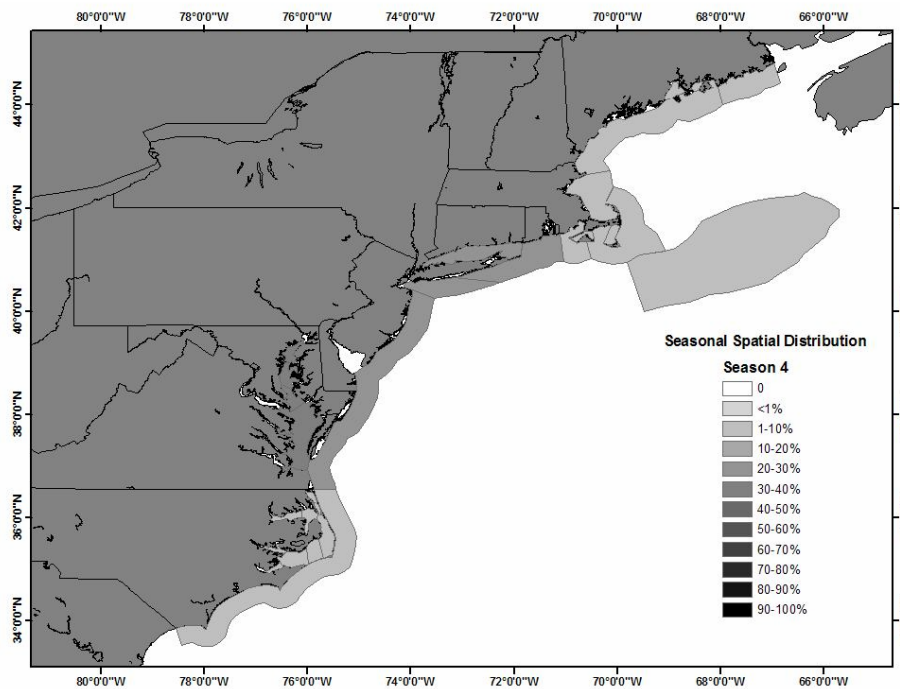


Figure D.29. Observed age-structure of striped bass catch within each region.

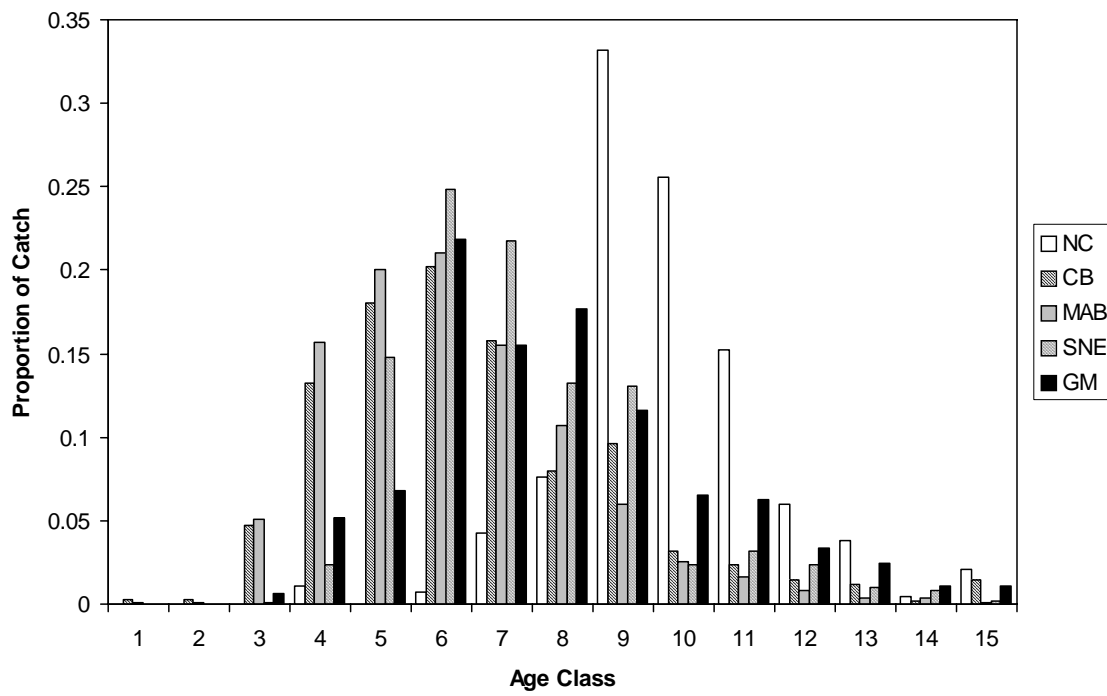
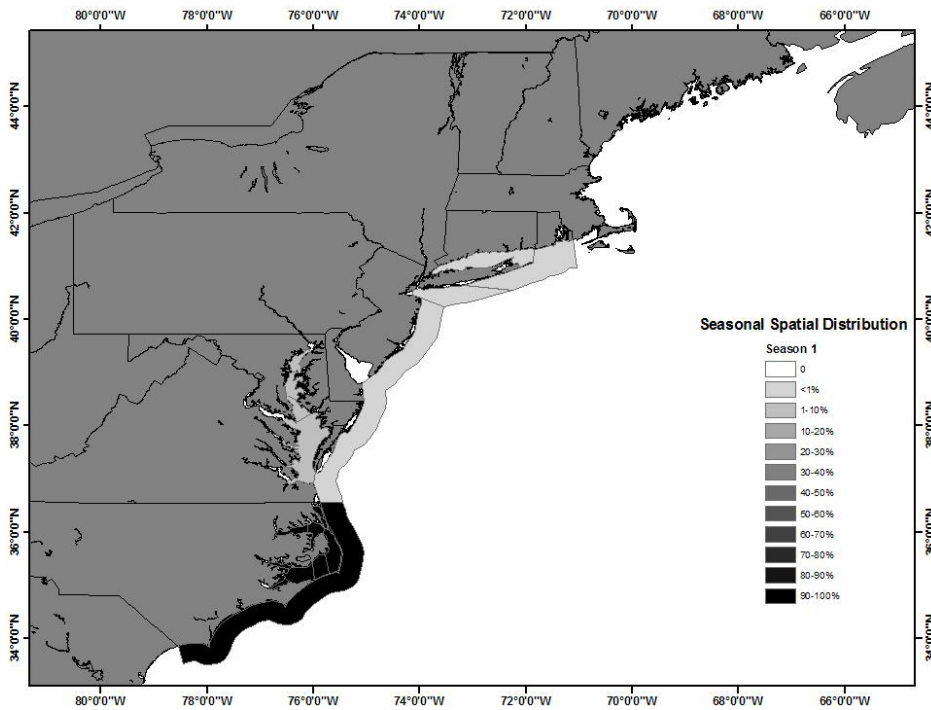


Figure D.30. Seasonal spatial distribution of weakfish based on landings data: a. Season 1; b. Season 2; c. Season 3; and d. Season 4.

a)



b)

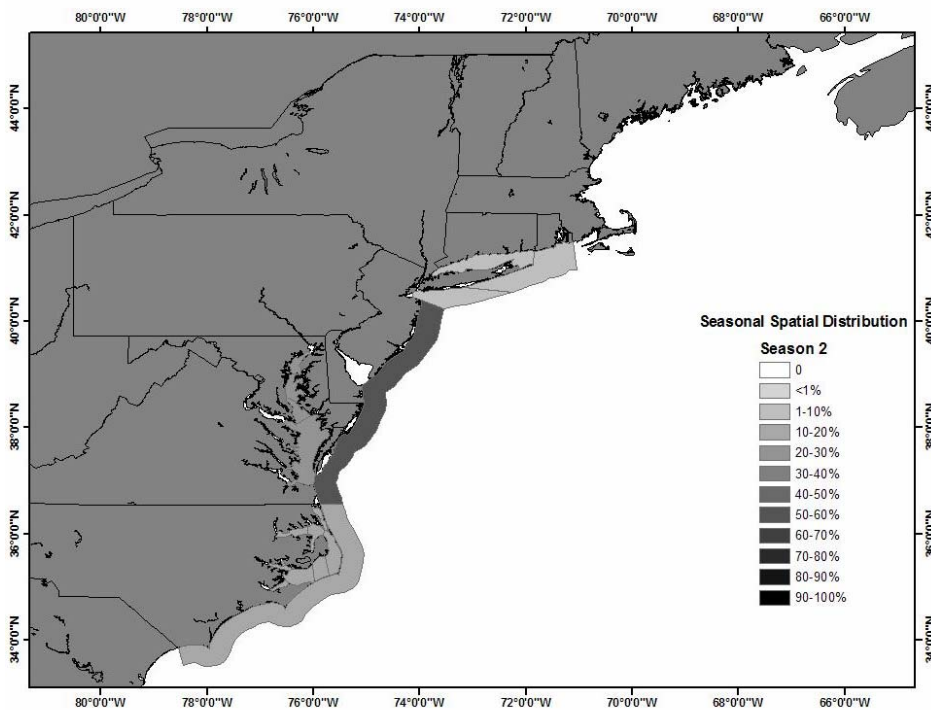
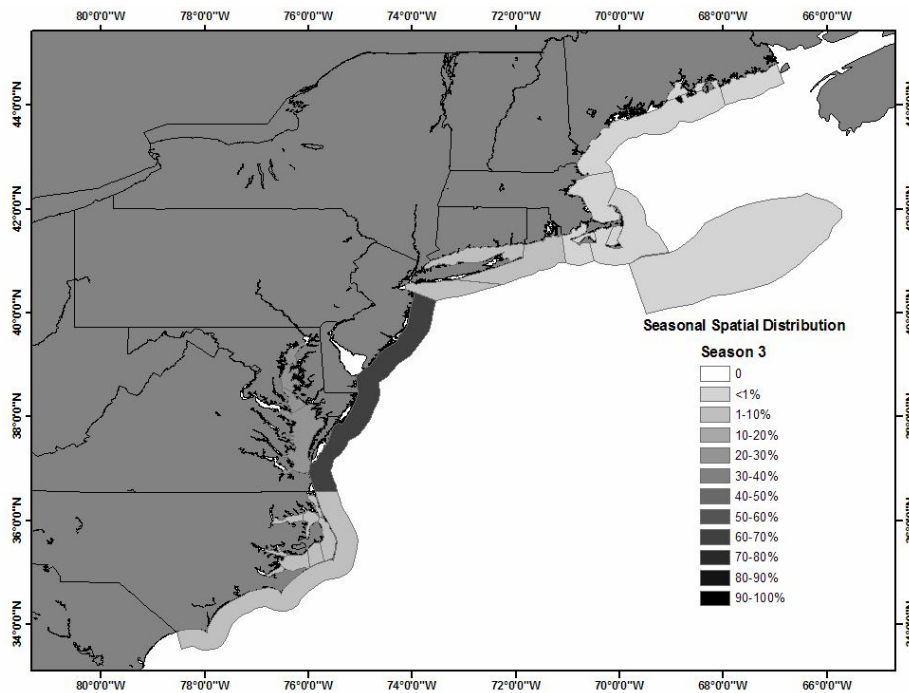


Figure D.30 (cont'd). Seasonal spatial distribution of weakfish based on landings data: a. Season 1; b. Season 2; c. Season 3; and d. Season 4.

c)



d)

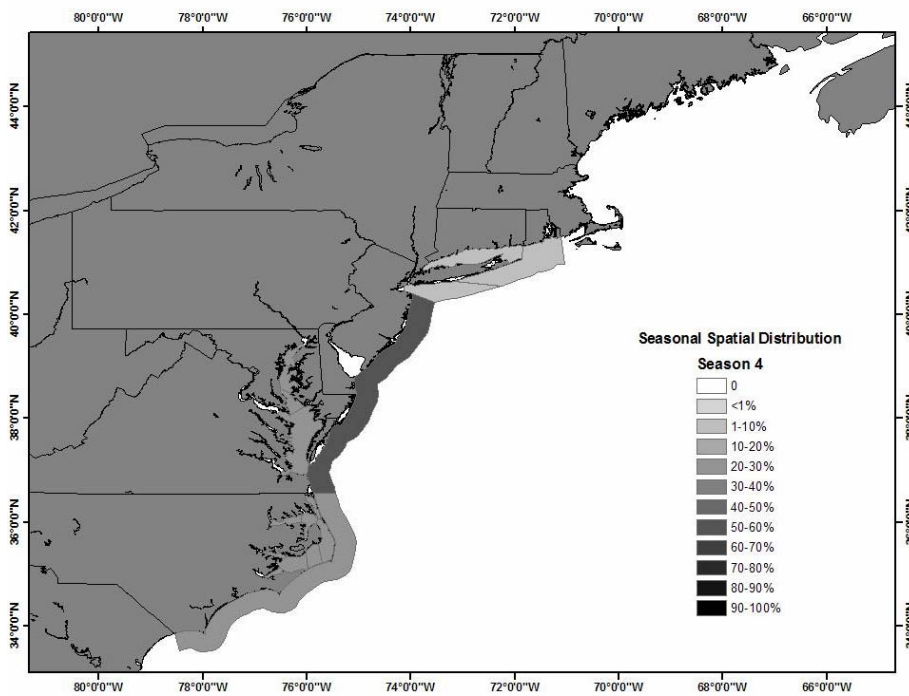


Figure D.31. Observed age-structure of weakfish catch within each region.

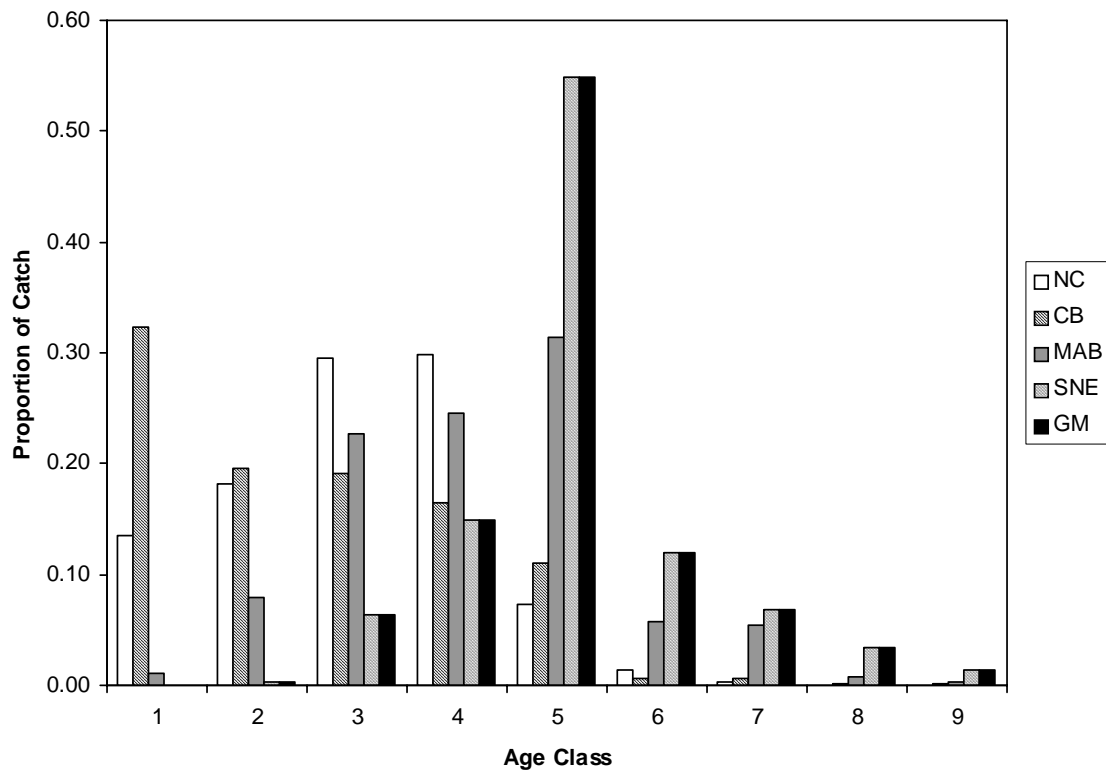
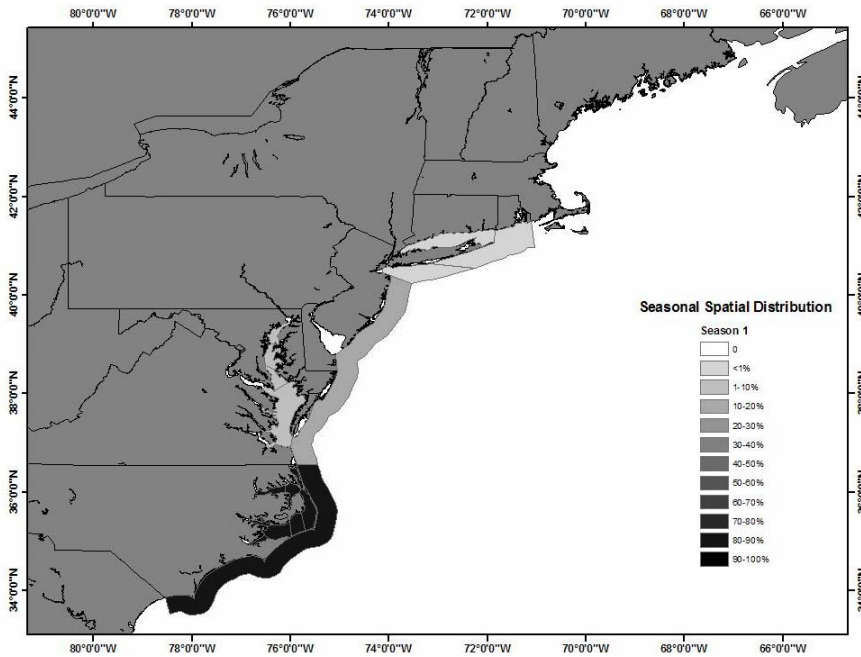


Figure D.32. Seasonal spatial distribution of bluefish based on landings data: a. Season 1; b. Season 2; c. Season 3; and d. Season 4.

a)



b)

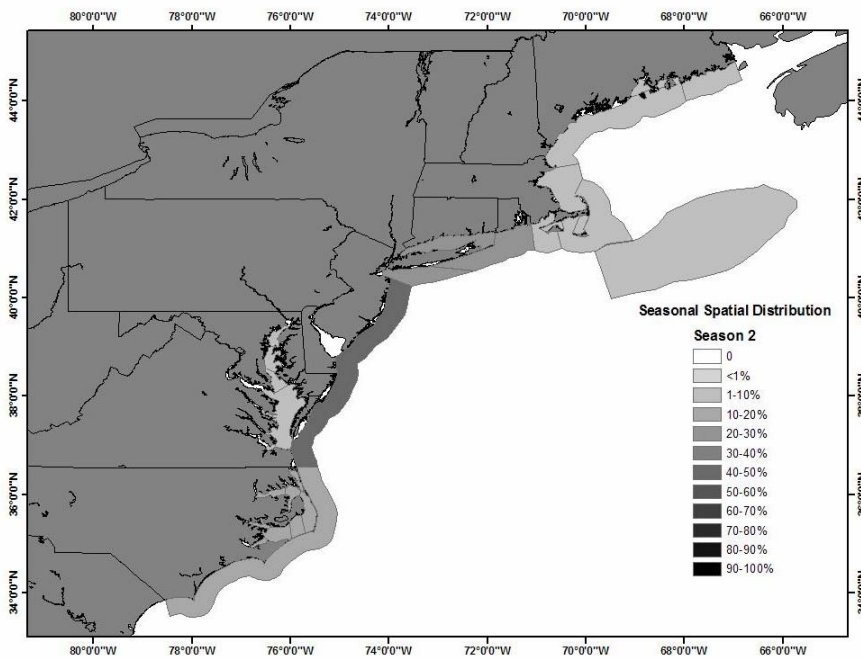
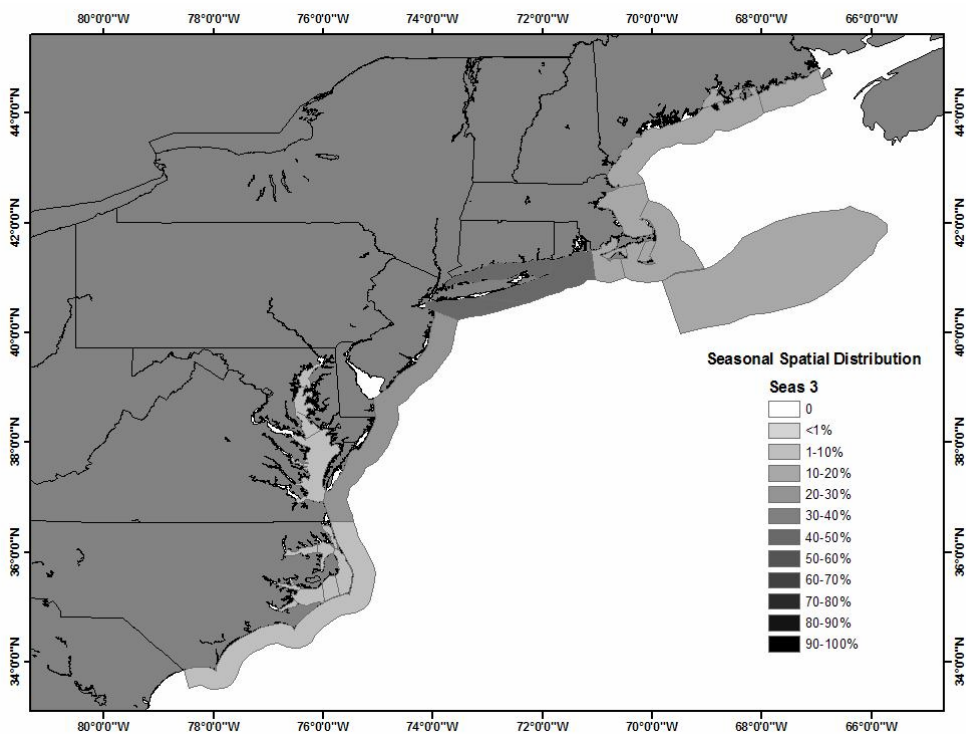


Figure D.32 (cont'd). Seasonal spatial distribution of weakfish based on landings data: a. Season 1; b. Season 2; c. Season 3; and d. Season 4.

c)



d)

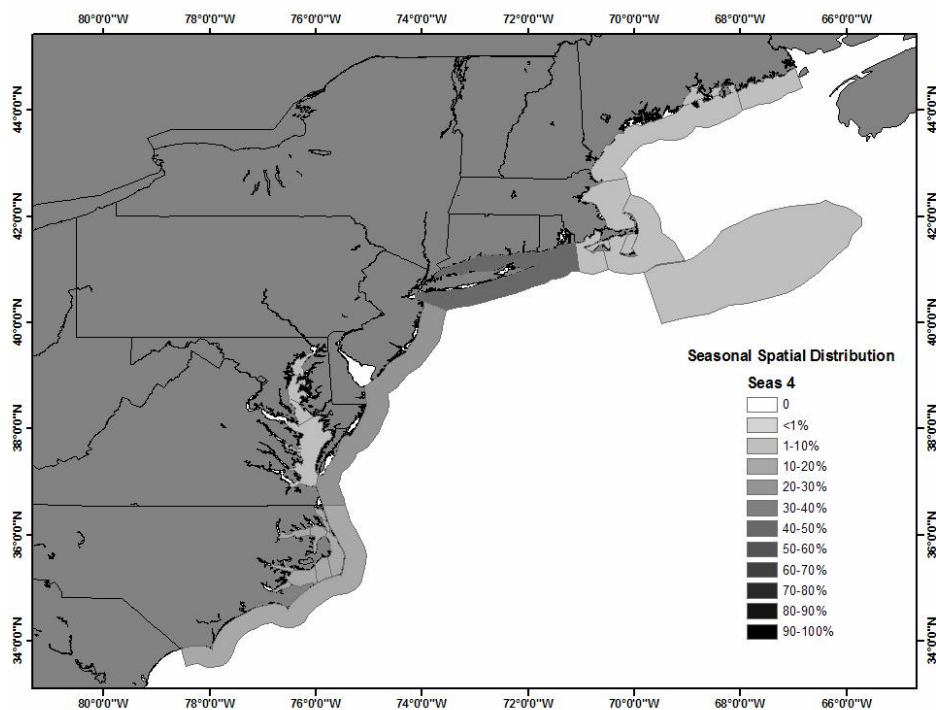


Figure D.33. Relative mean catch per tow of bluefish in each region for each season by the NMFS bottom trawl survey.

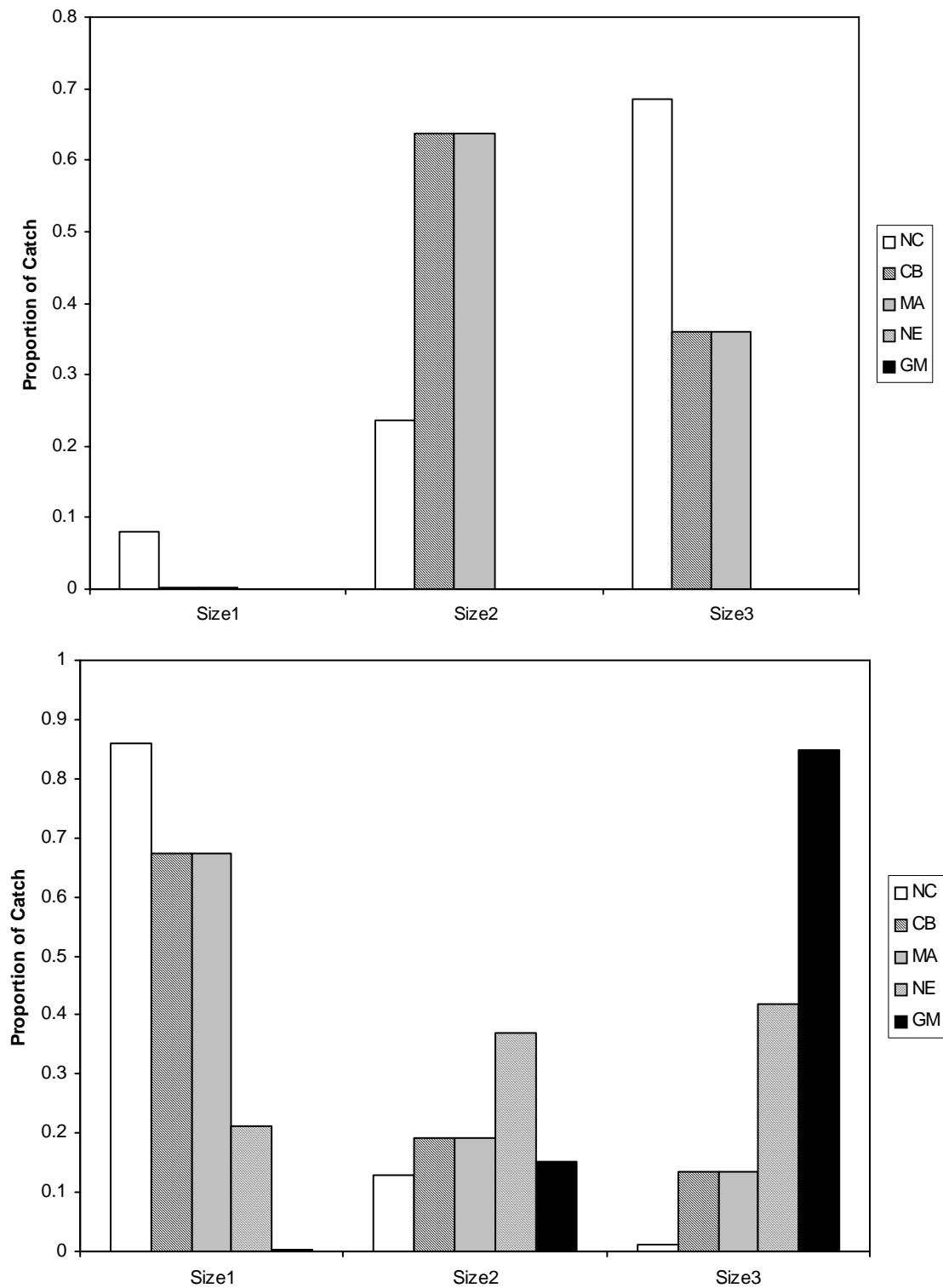
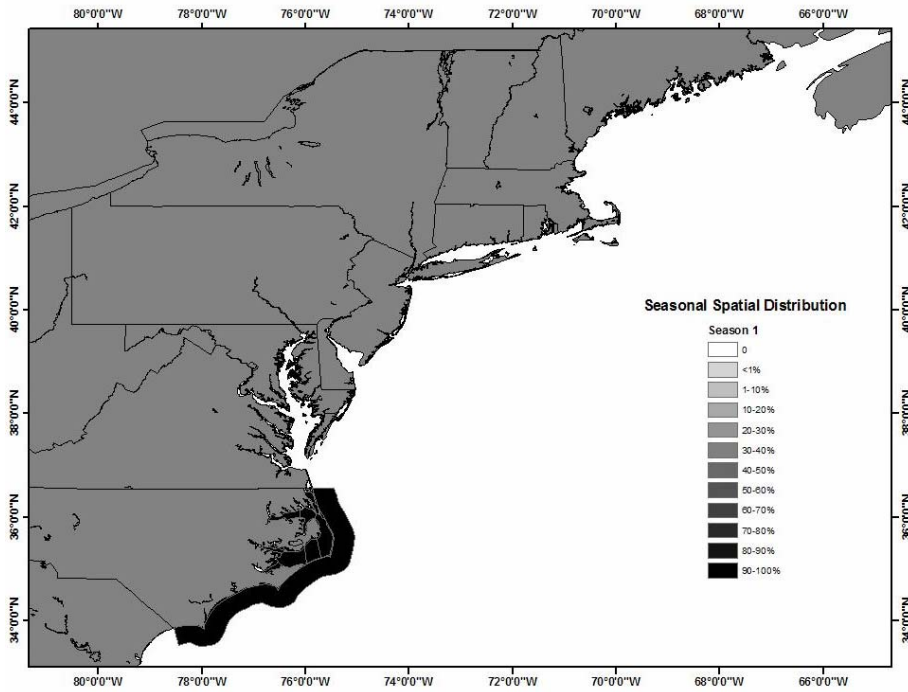


Figure D.34. Seasonal spatial distribution of menhaden based on landings data: a. Season 1; b. Season 2; c. Season 3; and d. Season 4.

a)



b)

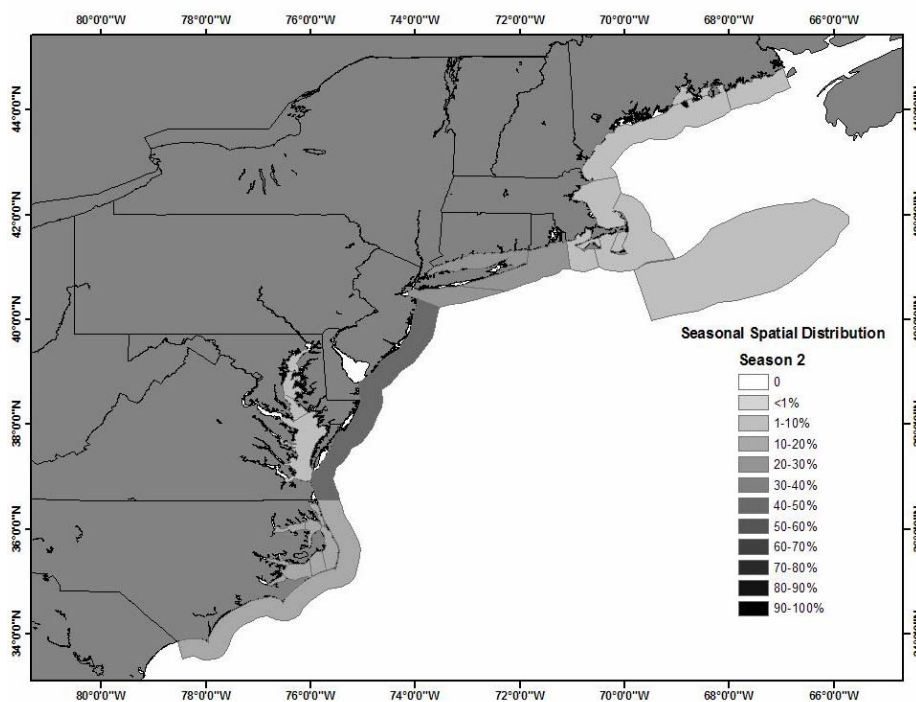
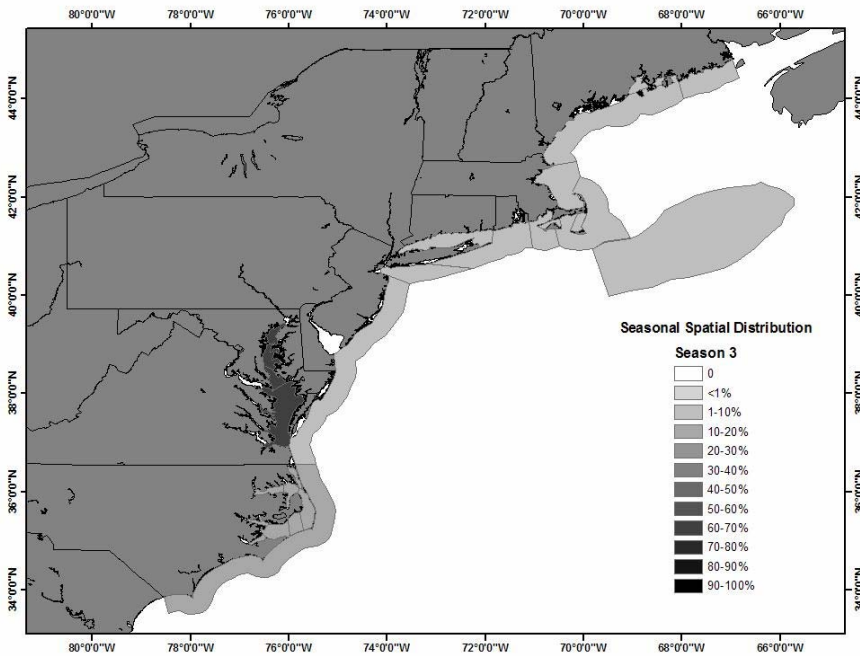


Figure D.34 (cont'd). Seasonal spatial distribution of menhaden based on landings data: a. Season 1; b. Season 2; c. Season 3; and d. Season 4.

c)



d)

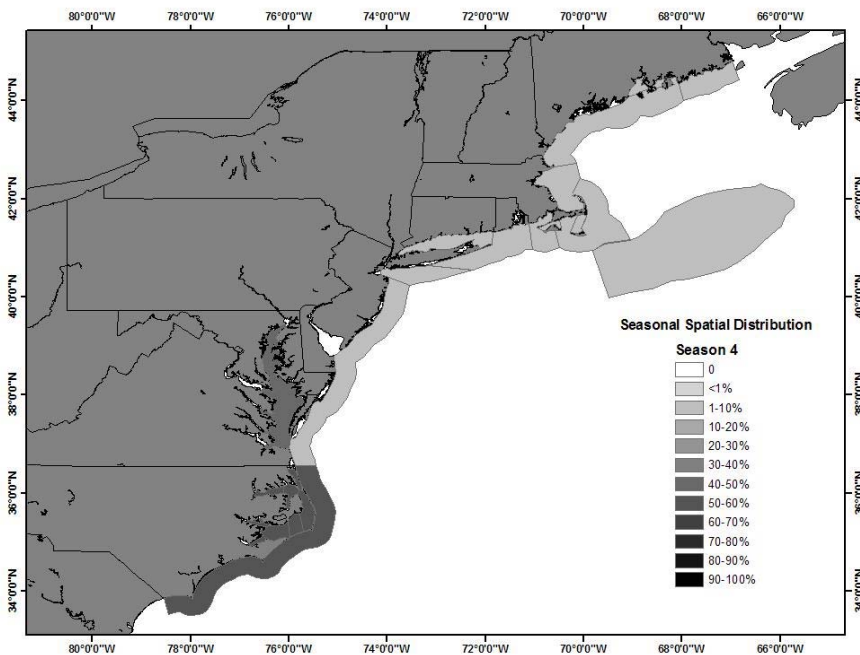


Figure D.35 (A.-C.). Seasonal spatial distribution of A) medium forage fish (primarily squid and butterfish), B) herrings (clupeids), and C) sciaenids (spot and croaker) from the mean catch per tow in each region from NMFS bottom trawl survey data.

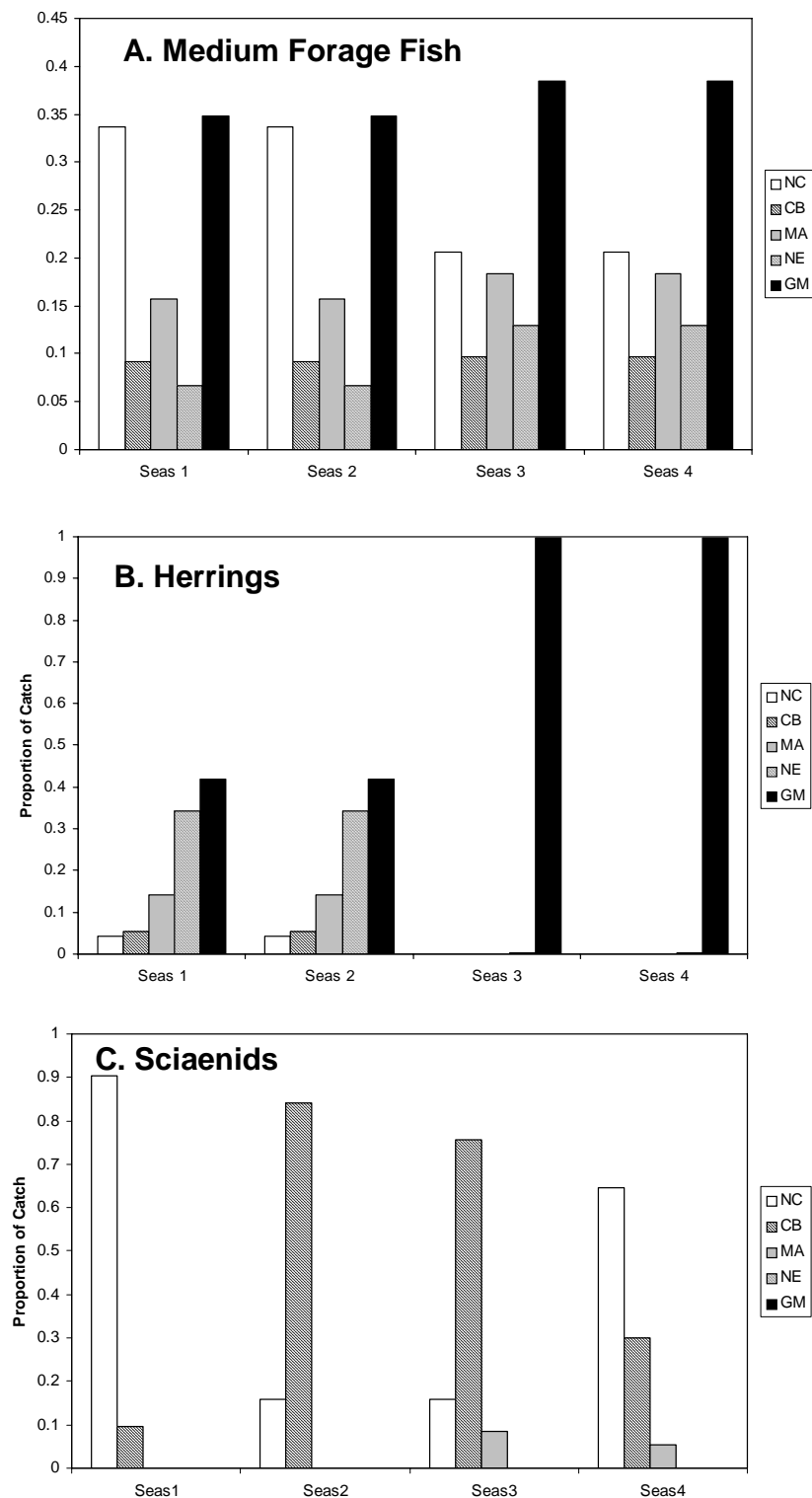


Figure D.36. Spatial distribution of anchovies, benthic invertebrates, benthic crustaceans and macrozooplankton.

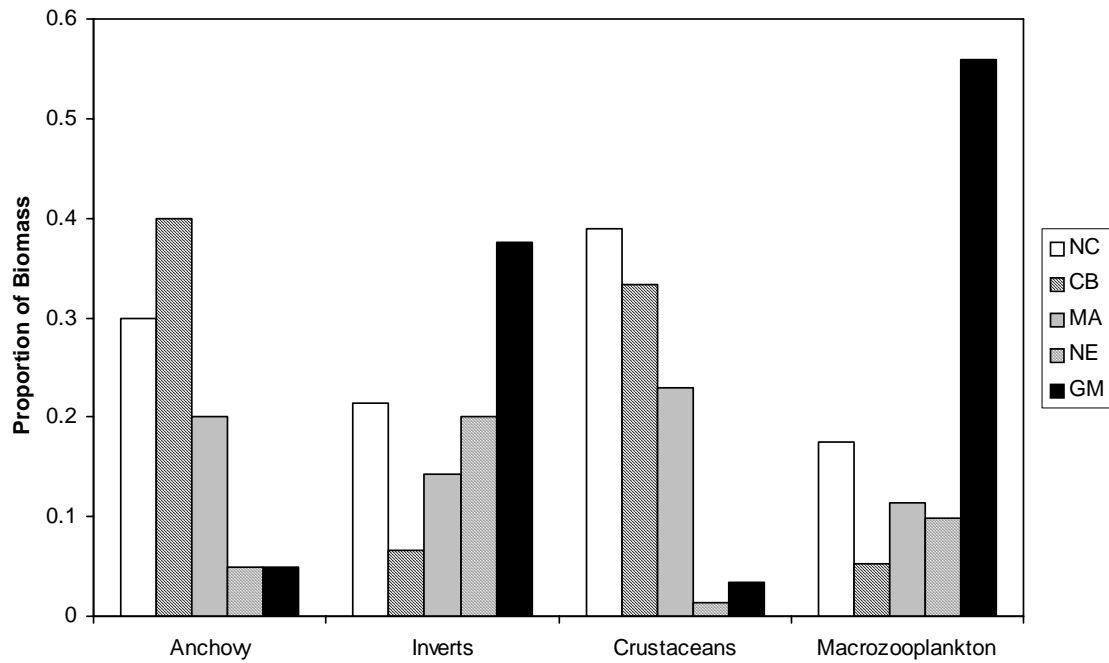


Figure D.37. Total population biomass (000 mt) for weakfish and striped bass.

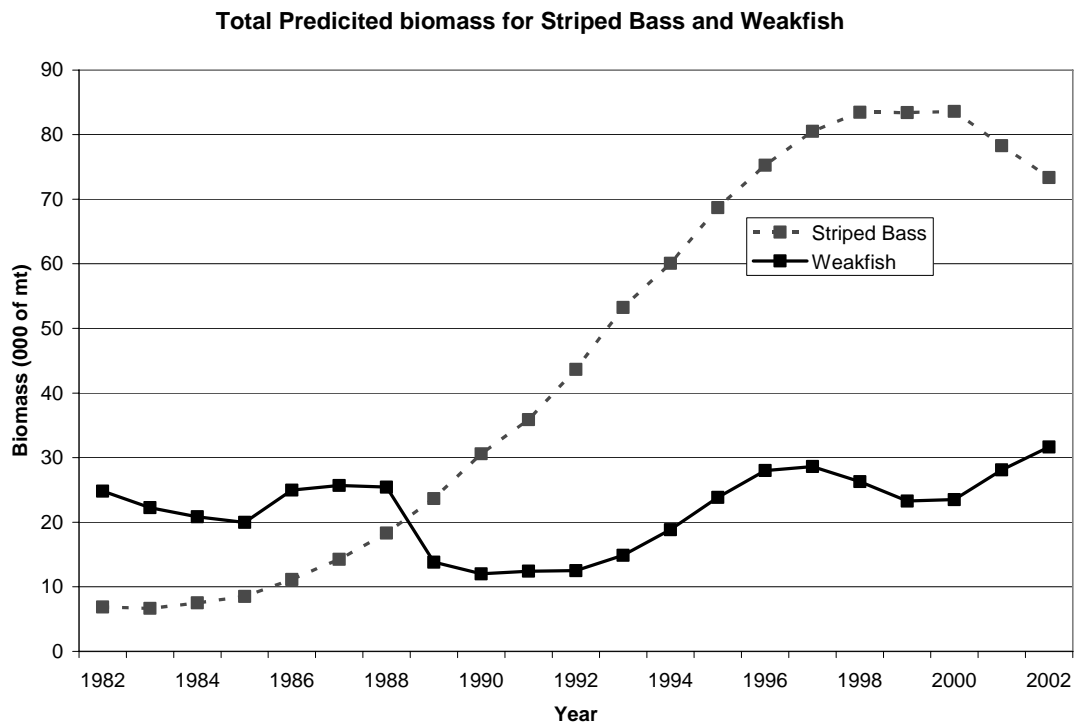


Figure D.38. Annual SSB (000 mt) for weakfish and striped bass.

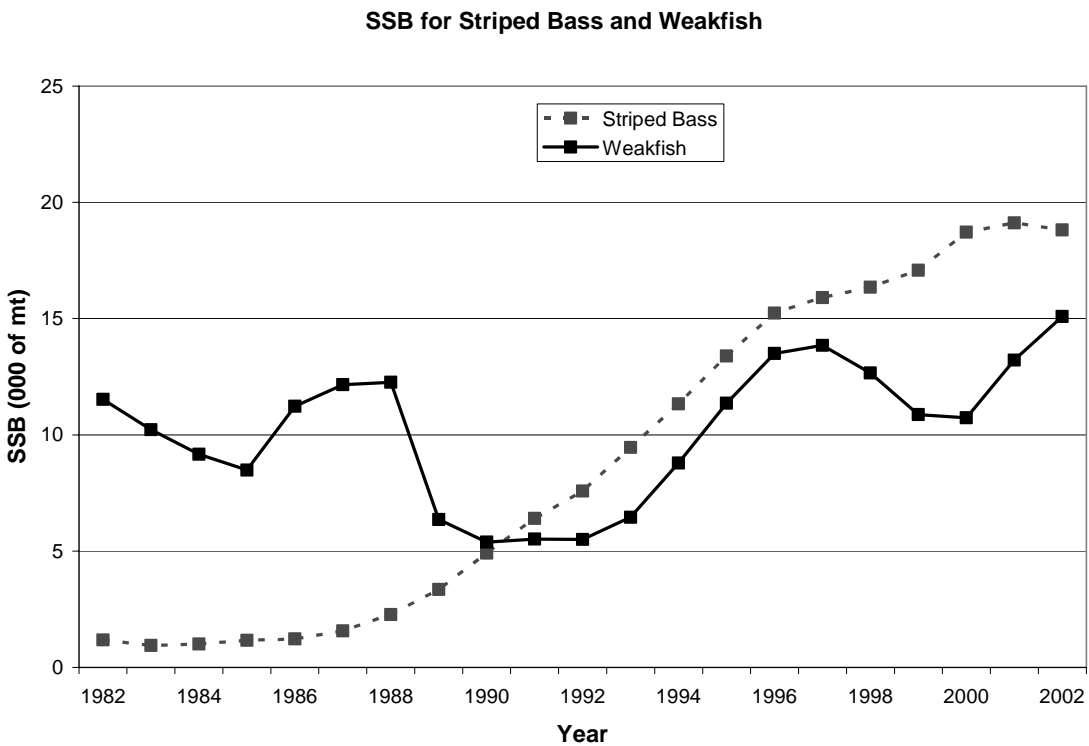


Figure D.39. Annual bluefish population biomass (000mt) by size class.

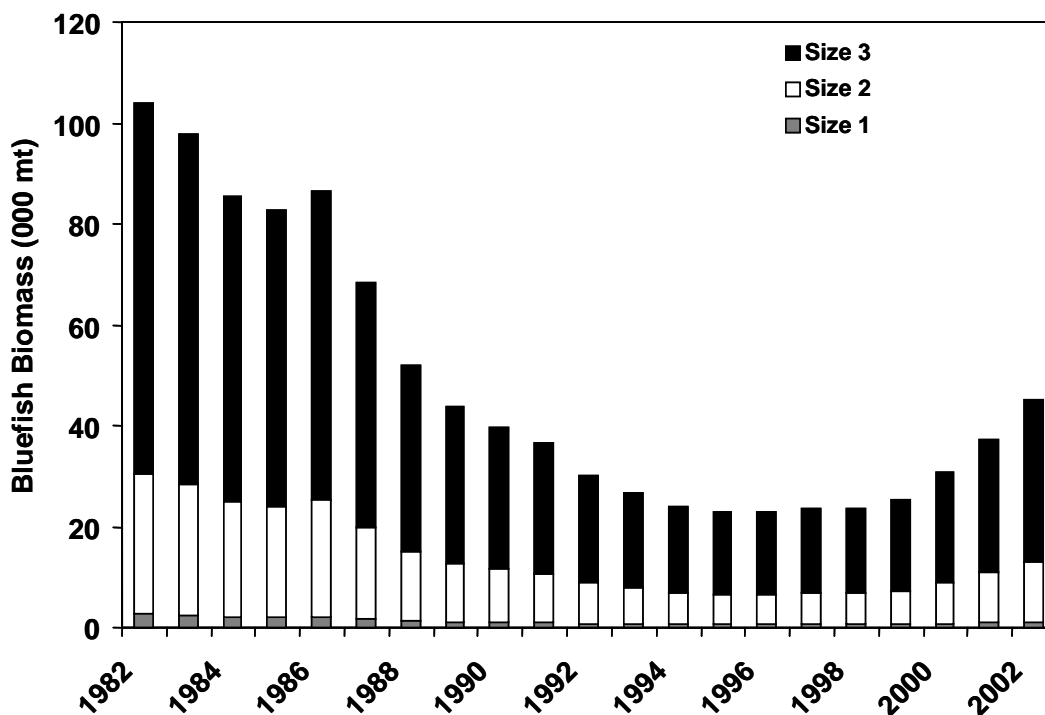


Figure D.40. Menhaden abundance at maturity (Age 2+, primary y-axis) and total menhaden abundance (secondary y-axis). Note the scale change on the secondary y-axis.

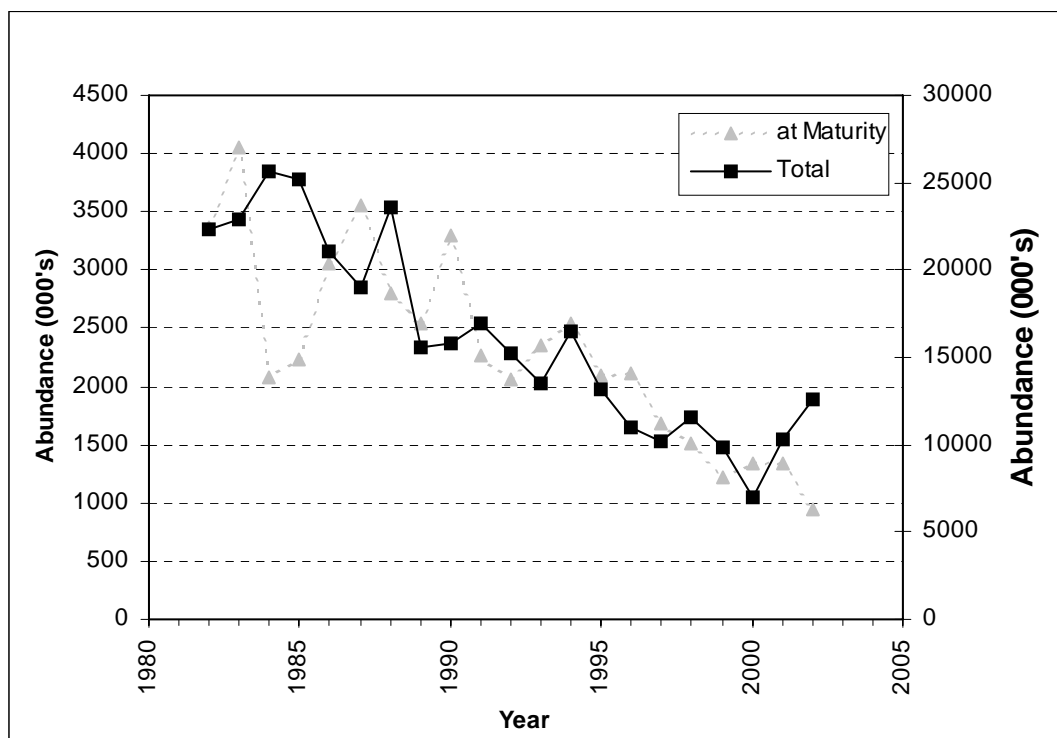


Figure D.41. Total menhaden SSB (primary y-axis) and population biomass (secondary y-axis) (000 mt). Note the scale change on the secondary y-axis.

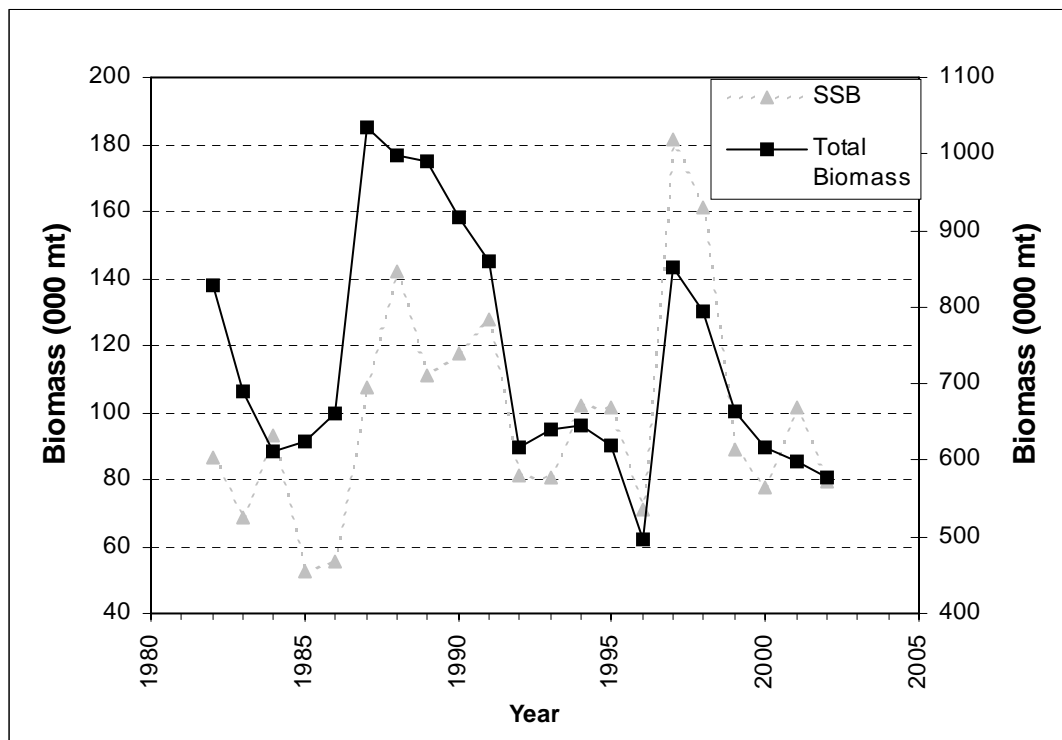


Figure D.42. Annual population biomass (000 mt) trends in MSVPA-X forage species.

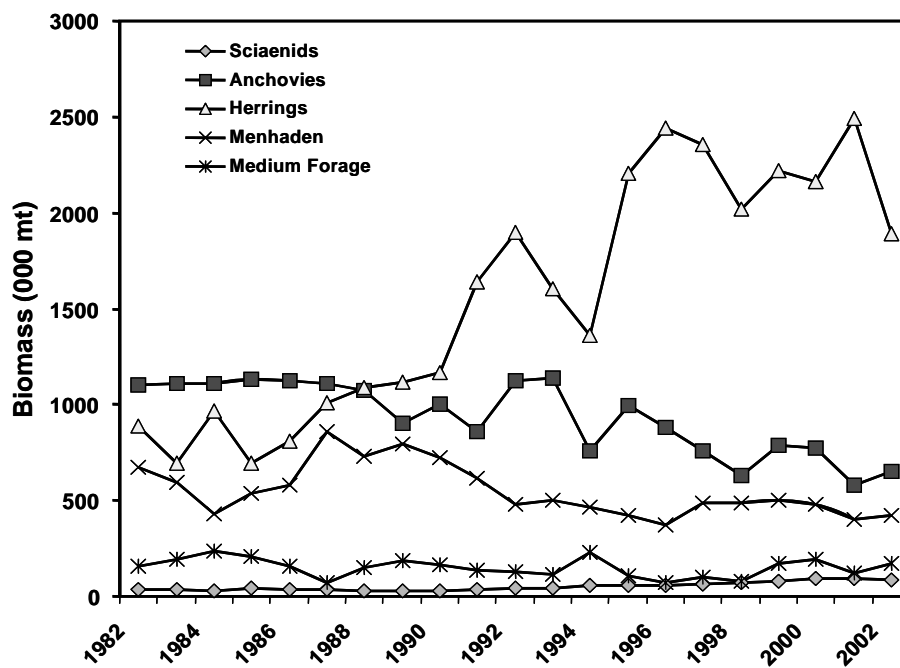


Figure D.43. Predicted average proportion of prey in striped bass diets.

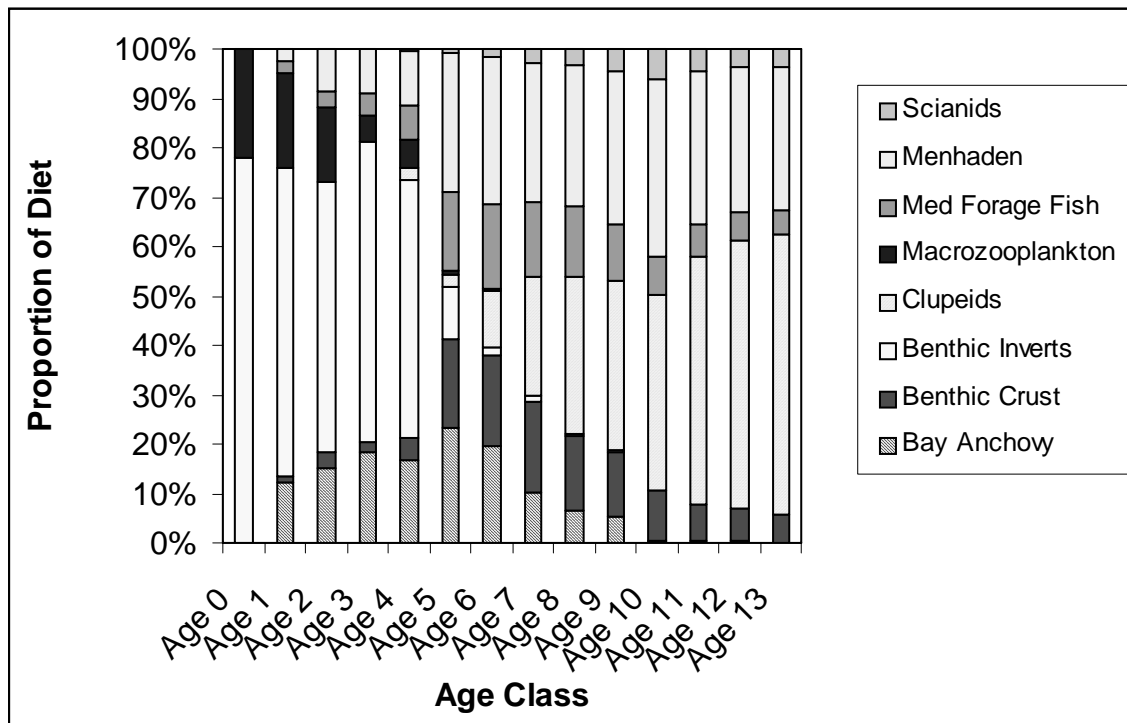


Figure D.44. Predicted average proportion of prey in weakfish diets.

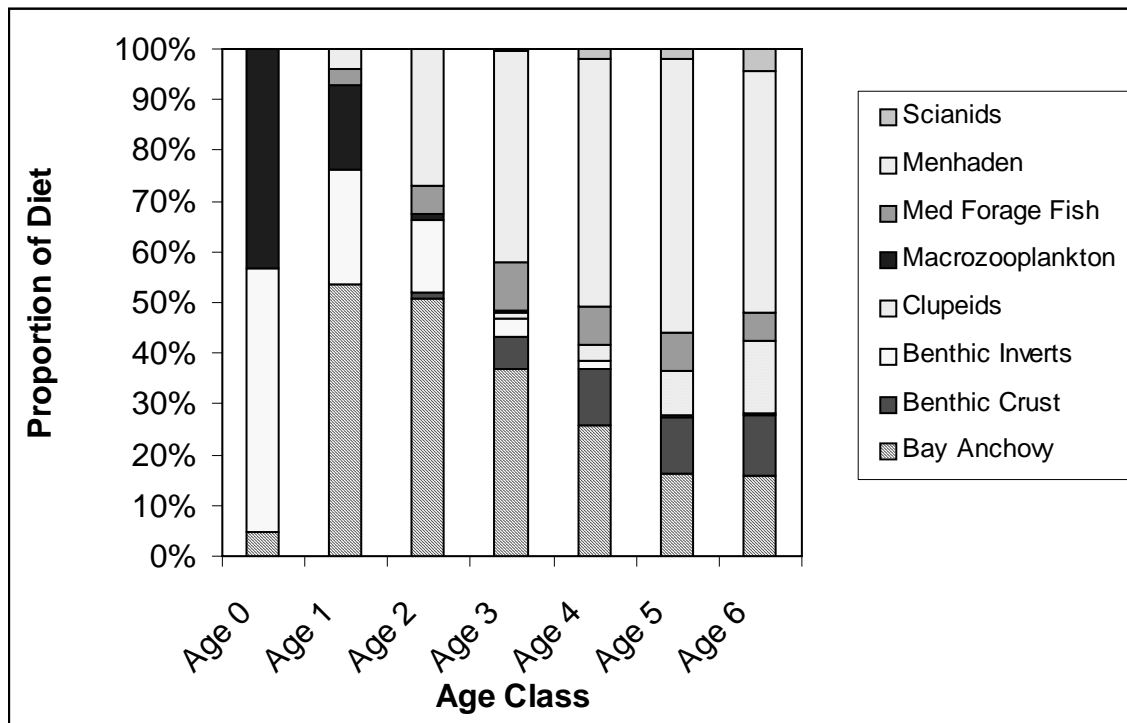


Figure D.45. Predicted average proportion of prey in bluefish diets.

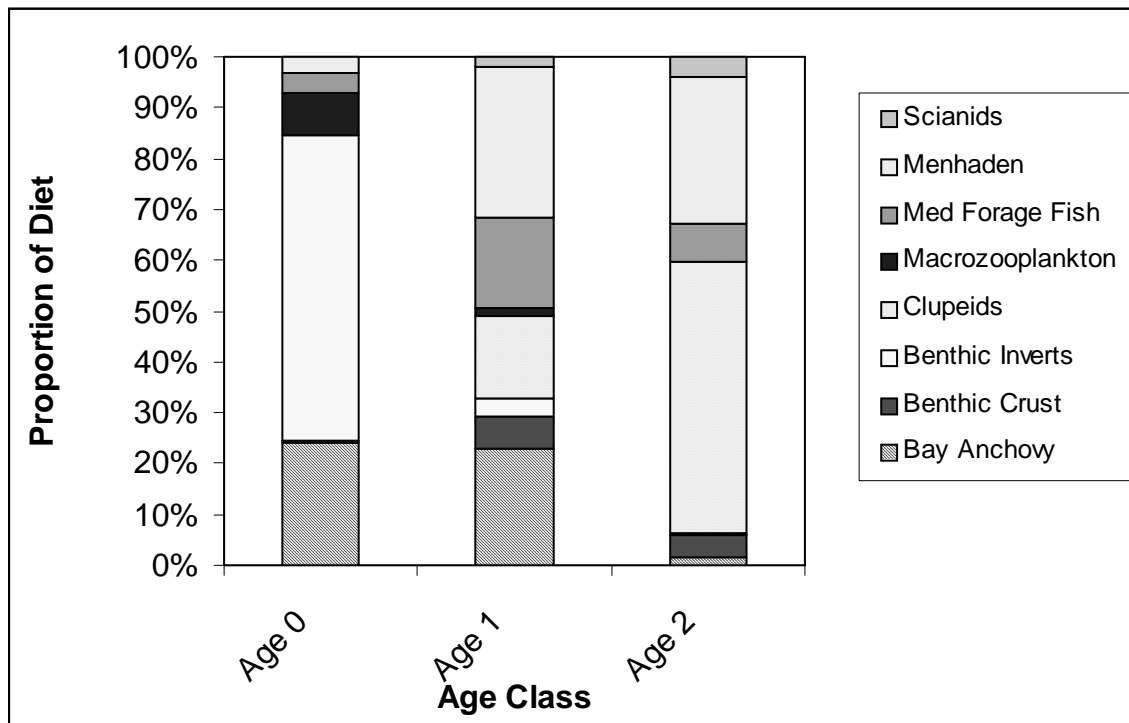


Figure D.46. Predicted total prey biomass consumed annually by all ages of striped bass.

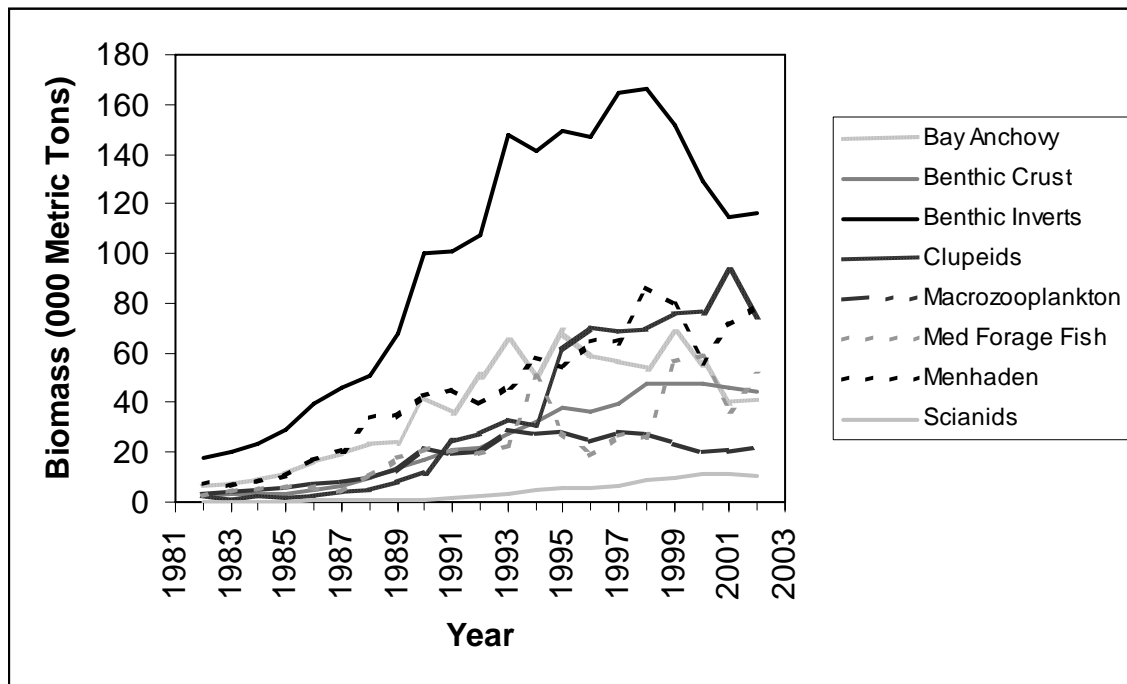


Figure D.47. Predicted total prey biomass consumed annually by all ages of weakfish.

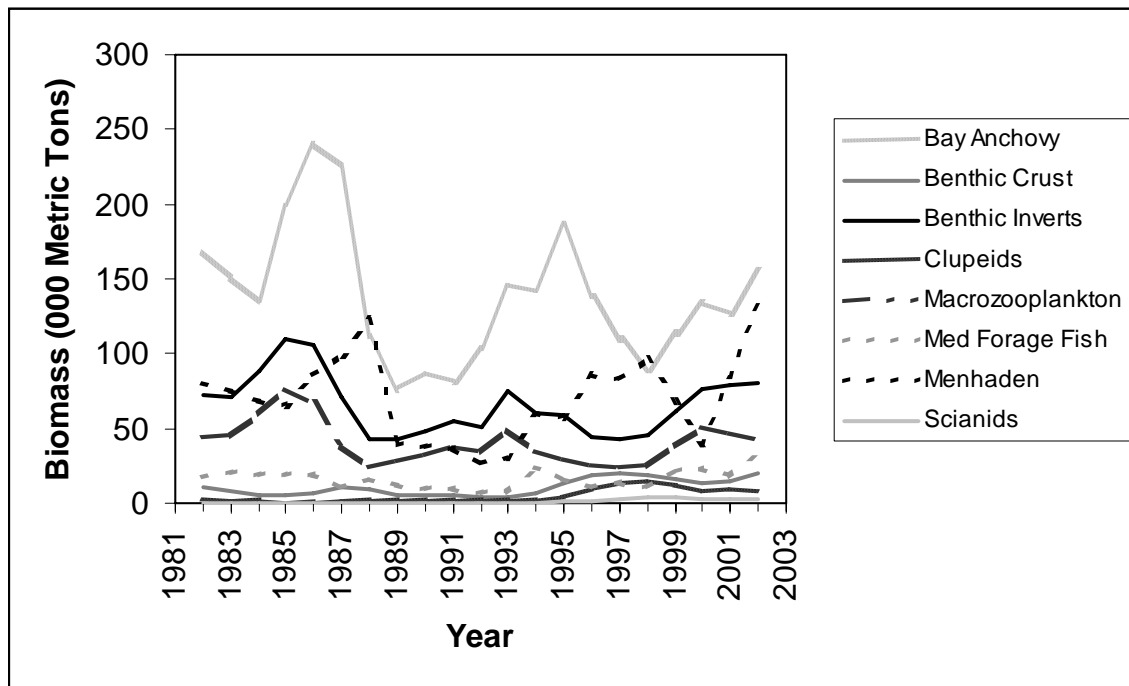


Figure D.48. Predicted total prey biomass consumed annually by all size classes of bluefish.

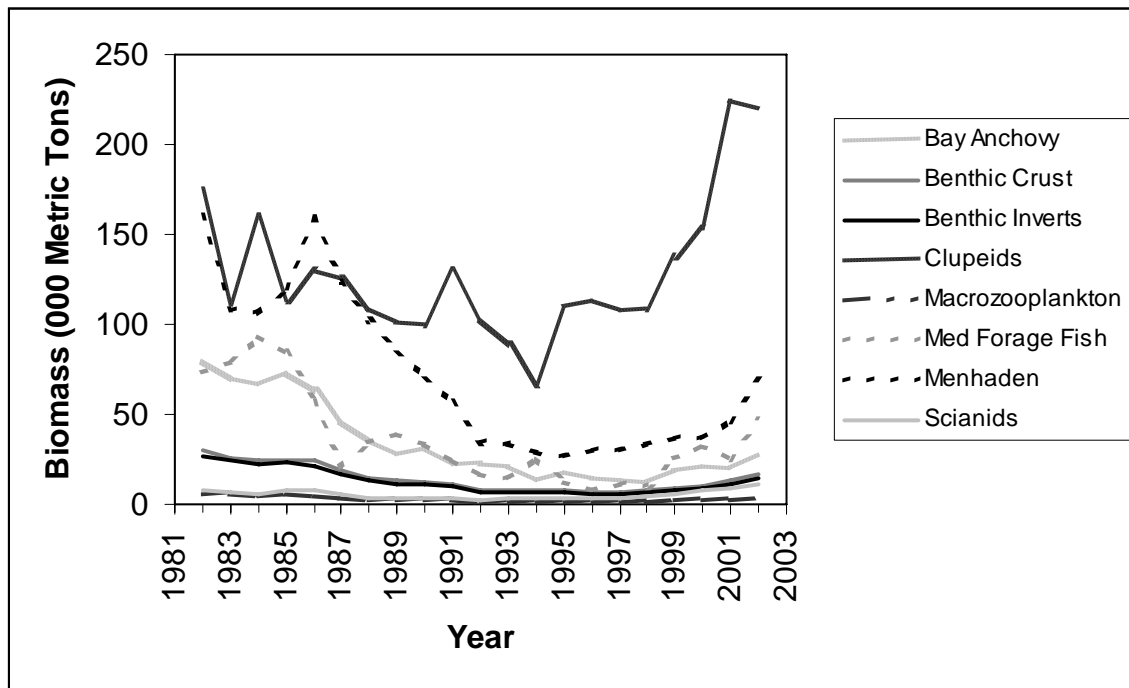


Figure D.49. Prey availability by species for Age 7 striped bass. Relative availability based on time series average.

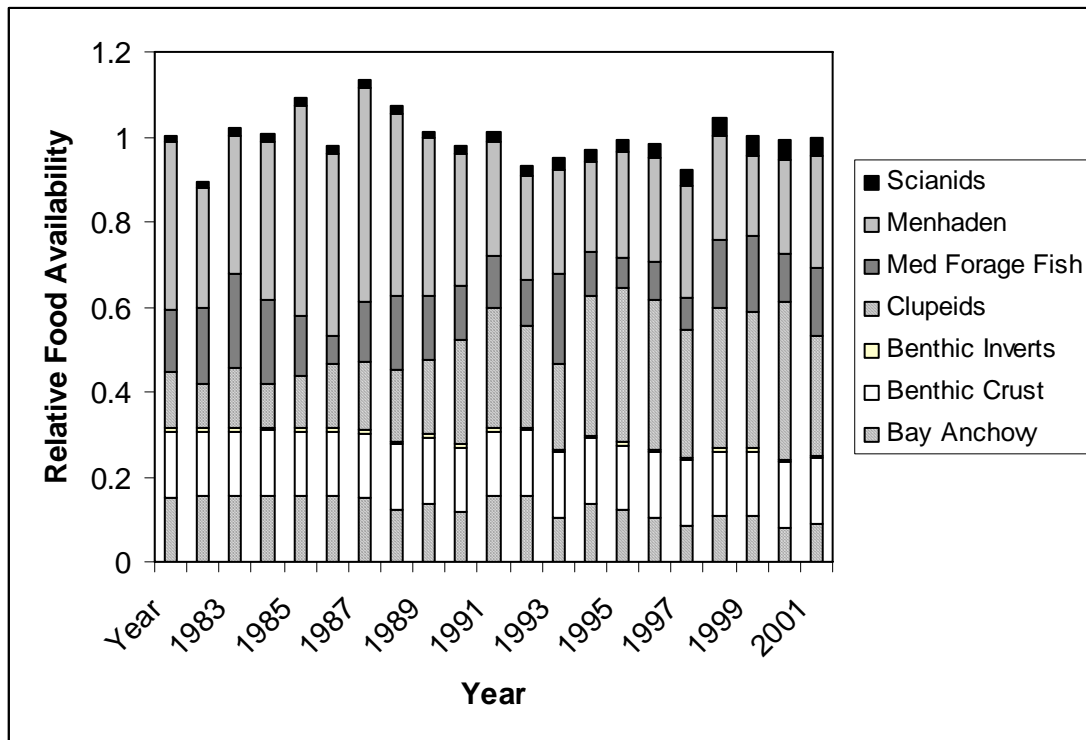


Figure D.50. Prey availability by species for age 4 weakfish. Relative availability is based on time series average.

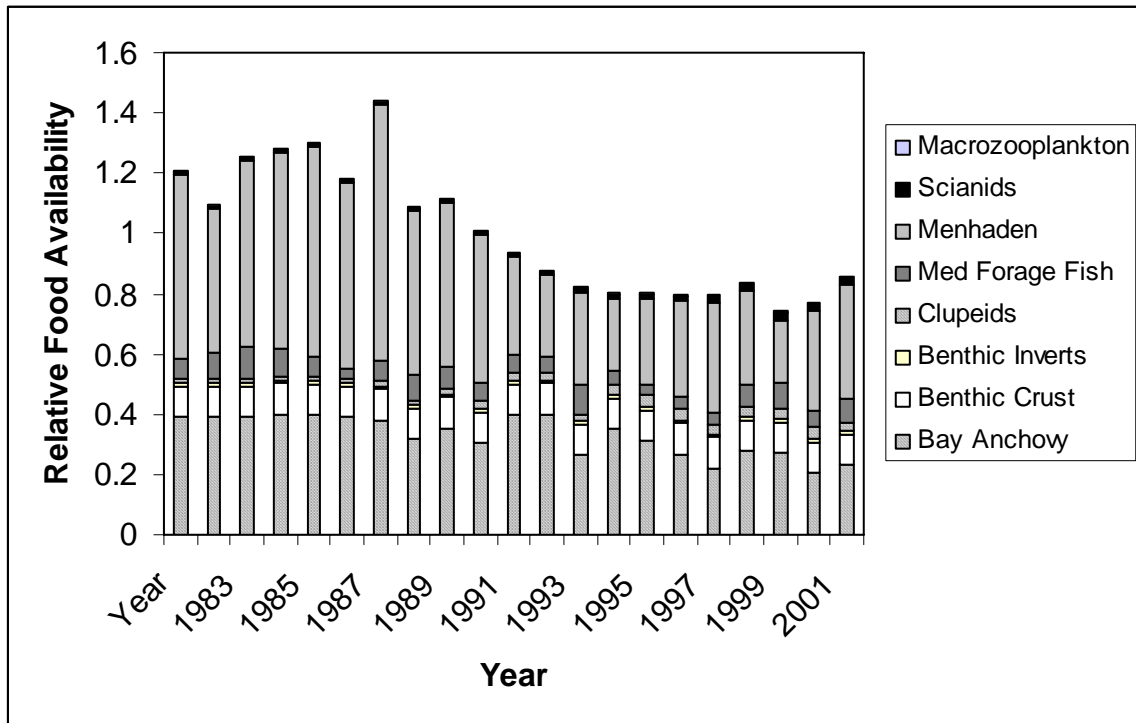


Figure D.51. Annual age-0 menhaden predation mortality (M2) by predator.

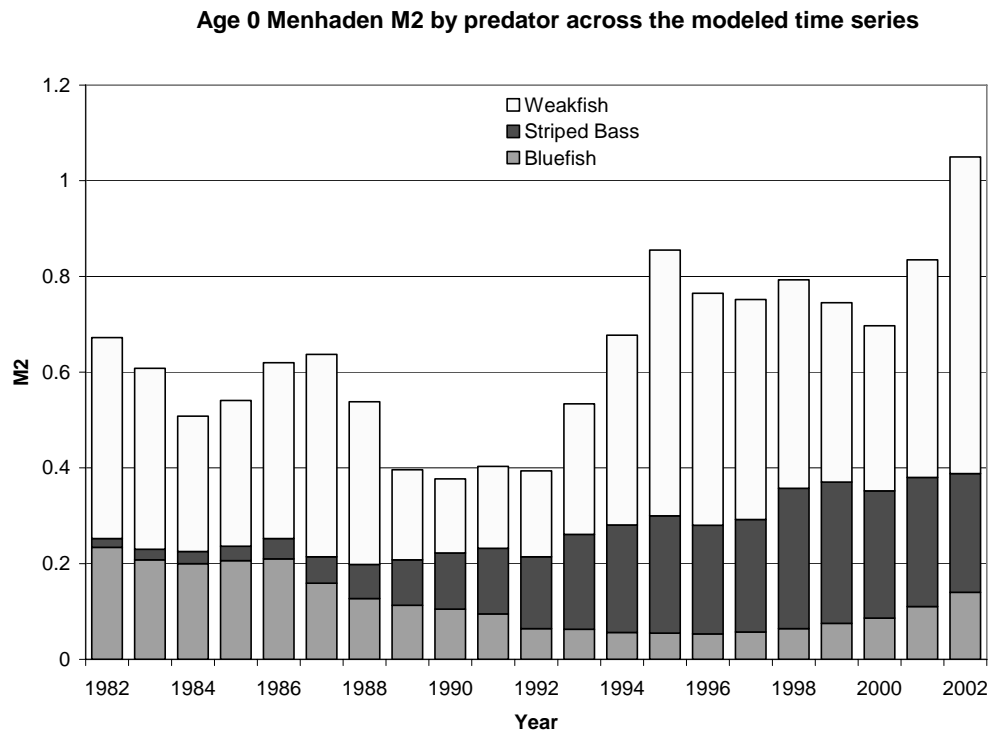


Figure D.52. Annual age-1 menhaden predation mortality (M2) by predator.

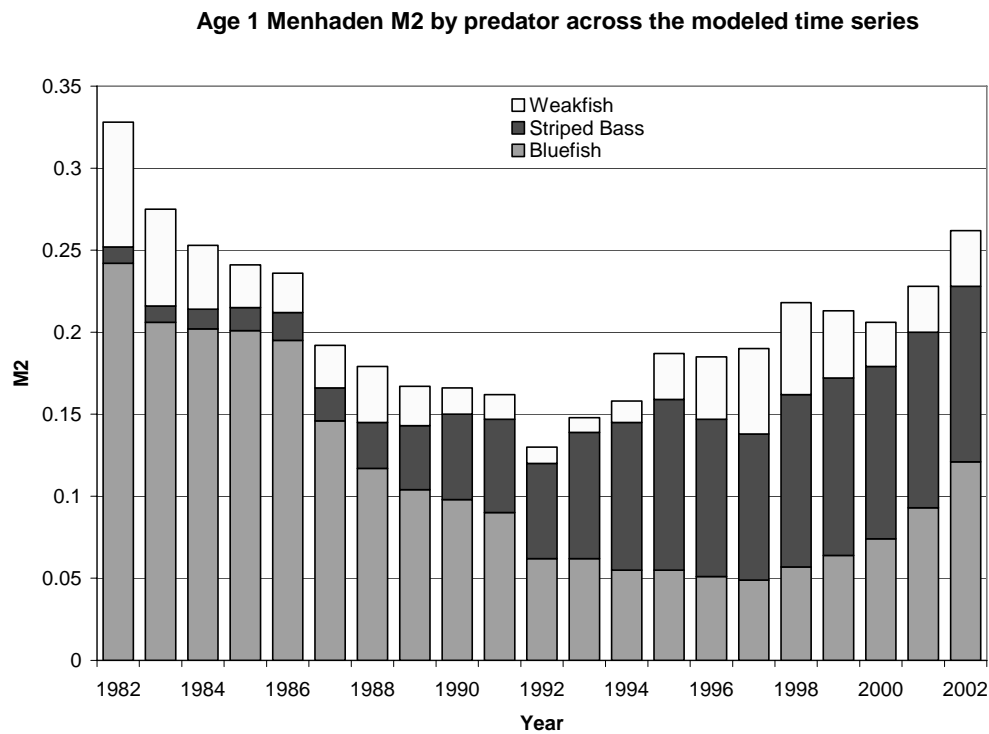


Figure D.53. Annual age-2 menhaden predation mortality (M2) by predator.

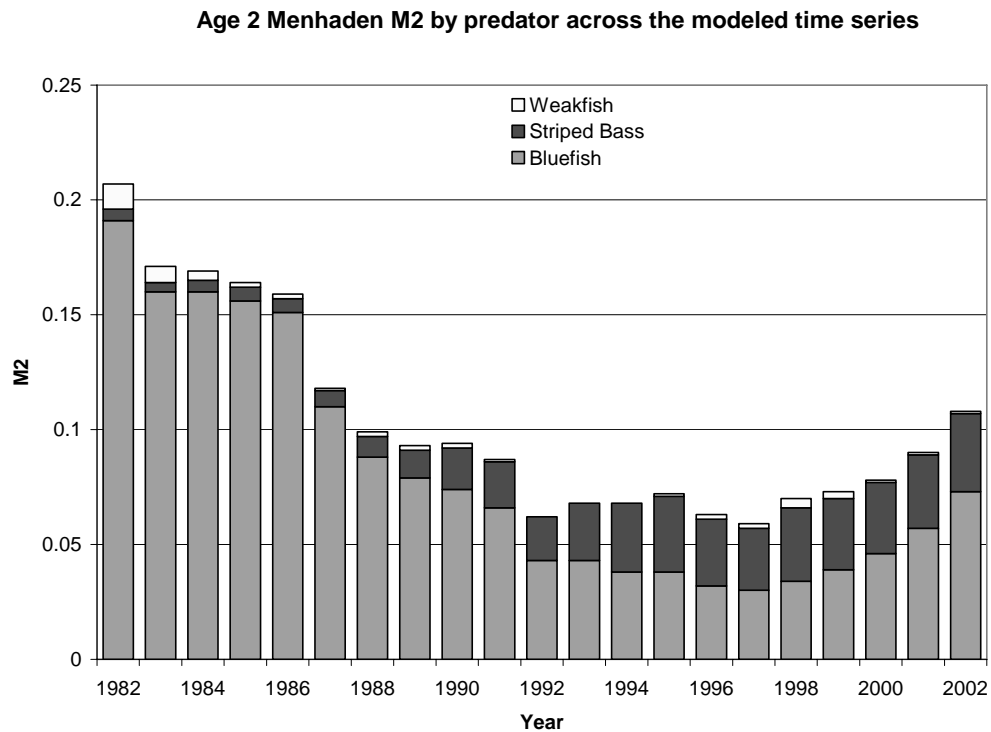
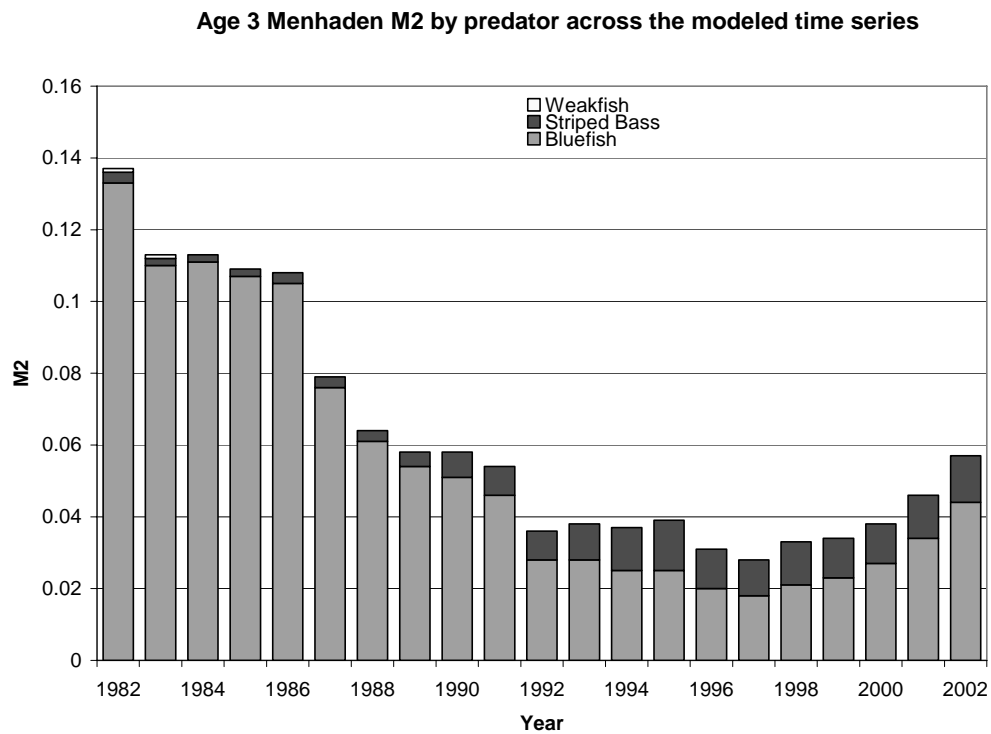


Figure D.54. Annual age-3 menhaden predation mortality (M2) by predator.



APPENDIX D1: SENSITIVITY ANALYSES

D1 1.0 SENSITIVITY ANALYSIS SUMMARY

The sensitivity of the MSVPA-X to changes in input is presented in this Appendix (D1). Several analyses were conducted to evaluate the sensitivity of the MSVPA-X to changes in input parameters. Specifically, sensitivity analyses of model to changes in “other natural mortality” (M1), prey type selectivity, prey size selectivity, predator weight-at-age, gastric evacuation rate parameters, predator and prey spatial overlap, and the addition and deletion of ‘other prey’ items are presented. An examination into the retrospective bias of the model in terminal year estimates is presented. In addition, a test of the forecast model is also presented that investigates the ability of MSVPA-X to reproduce past observations.

D1 1.1 RETROSPECTIVE BIAS

A series of retrospective runs were conducted to investigate bias in terminal year estimates for explicitly modeled species. Retrospective analyses were run by adjusting the terminal year in the configuration screen and comparing results for several years. Presented are the retrospective results of these runs for weakfish, striped bass, and menhaden fishing mortality (F) and spawning stock biomass (SSB). An examination of potential bias in predation mortality (M2) for menhaden is also presented.

Results suggest little retrospective bias in menhaden fishing mortality and spawning stock biomass (Figures D1.1 and D1.2 respectively). While a persistent bias is not evident in striped bass fishing mortality or spawning stock biomass (SSB) (Figures D1.3 and D1.4), large changes in terminal year estimates are observed. Similarly, weakfish fishing mortality (F) and SSB do not show a consistent bias in the terminal year (Figures D1.5 and D1.6), but large differences in both SSB and F are noted in the terminal years. M2 for menhaden is also variable in the terminal year; however, a persistent bias in the estimation of predation mortality is not apparent (Figure D1.7). Overall the results for both striped bass and weakfish are not surprising given the retrospective output in the single-species models for each (ASMFC, 2003; ASMFC, 2004; and Kahn, 2002).

D1 1.2 DROPPING “OTHER PREY” ITEMS

A sensitivity analysis to examine the effects of removing important “other prey” items from the model was conducted. To remove the selected prey item, the type preference for a given item was set to zero. Relative ranks of the remaining items were kept constant by adjustment within the type preference input. Items removed included bay anchovy, clupeids (herrings and others), and medium forage fish. Shown are the effects of these removals on menhaden M2, SSB and the average diet composition for striped bass across the time series.

Removal of prey items causes some departure from the base run with respect to menhaden predation mortality (Figure D1.8). The exclusion of anchovy produces the most substantial relative effect. In general, removal of prey items increases predation mortality on menhaden,

particularly early in the time series. However, no effect is noted on modeled SSB for menhaden (Figure D1.9) despite an increase in predation mortality.

Diet composition is also affected by removal of prey items for striped bass. As expected, striped bass diet composition changes as prey items are removed (Figures D1.10-D1.13). Removing clupeids appears to create the greatest effect on diet composition for striped bass, especially within the older age classes.

Predation mortality by predator across the time series was also examined (Figures D1.14-D1.17). The results suggest that the importance of striped bass consumption on M2 for menhaden diminishes when other prey items are removed. Weakfish consumption increases with removal of some items. Bluefish consumption of menhaden changes little until clupeids are removed.

D1 1.3 CHANGE IN M1

“Other natural mortality” or M1 is a component of natural mortality related to all natural mortality causes other than predation. M1 usually constitutes a smaller component of total M for prey species and is a larger fraction or a full value of total natural mortality for a predator. Misspecification of M1 will generate some bias in total natural mortality estimates and consequently, bias in population abundance estimates. The sensitivity of a number of MSVPA outputs was investigated by varying M1 systematically on the range of 0.1-0.5 year⁻¹ with a step of 0.1 and M1=0.3 as a base or reference value. Corresponding changes in total menhaden abundance, biomass, spawning biomass, abundance of ages-0 and -1, predation M and average F for fully recruited ages are reported below.

D1 1.3.1 Age-0, age-1 and total menhaden abundance

Menhaden total abundance is lowest when M1=0.1. Increasing M1 leads to increased absolute abundance of menhaden (Figure D1.18) as expected. Changing M1 from 0.1 to 0.5 increased abundance approximately twofold. The relationship between changes in M1 and total abundance is slightly nonlinear, exhibiting larger relative changes in abundance as M1 increases (Figure D1.19). Consequently, population size estimates will be biased more by a positive bias in M1 than by a negative bias in M1 (e.g., the absolute change in population estimate will be larger when M1 increases by 50% than when it declines by 50%). Changes in absolute abundance of age-0 and age-1 groups are similar in direction and scale, with age-0 abundance responding at a slightly higher rate to the change in M1 (Figures D1.20 and D1.21).

D1 1.3.2 Menhaden total biomass and spawning stock biomass

Since total biomass is a product of abundance and weight-at-age, biomass responses to changes in M1 are similar to total abundance responses. Minimum values of biomass are estimated at M1=0.1 and biomass increases as M1 increases (Figure D1.22). Spawning stock biomass responses are similar to those for total biomass (Figure D1.23). Both total biomass and spawning stock biomass exhibit a slightly lower response rate to changes in M1 than does total abundance.

D1 1.3.3 Average fishing mortality for fully recruited age groups

Changing M1 values lead to changes in fishing mortality that are opposite the changes in biomass and abundance. The lowest levels of M1 produce the highest estimates of fishing mortality and vice versa (Figure D1.24). Changes in fishing mortality are strictly proportional to changes in M1, which was predicted. The relative magnitude of change in F is substantially lower than that of the biomass and abundance (i.e., the F estimate is less sensitive to changes in M1 compared to biomass and abundance).

D1 1.3.4 Predation mortality (M2) of ages 0 and 1 menhaden

Predation mortality has responded to changes in M1 similarly to the average fishing mortality – an increase in M1 causes a decline in estimated predation mortality and vice versa (Figures D1.25 and D1.26). Predation mortality changes proportionally to changes in M1. The relative magnitude of change in M2 is similar to changes in fishing mortality and is substantially lower than that of biomass and abundance. Consequently, M2 estimates are less sensitive to changes in M1 compared to biomass and abundance.

D1 1.3.5 Conclusions

In general, the effect of ‘other mortality’ on estimated parameters of the menhaden population, such as abundance, biomass and spawning biomass, and fishing and predation mortality, is predictable and modest to low in magnitude. An increase in M1 leads to higher values of population size (numbers at age, biomass, spawning biomass) and lower values of predation and fishing mortalities. While changes in fishing and predation mortalities are symmetrical and proportional to changes in M1, population size parameters respond to changes in M1 nonlinearly, with greater changes following larger values of “other mortality”. Consequently, population size parameters seem to be more sensitive to changes or misspecifications of M1 than predation and fishing mortality estimates. A larger bias would be expected in population size estimates when M1 is overestimated.

D1 1.4 EVACUATION RATES

Consumption rates of fishes can be estimated given information on gastric evacuation rates and stomach contents (Elliott and Persson, 1978). Gastric evacuation rates are influenced by a variety of factors including temperature, size of predator, prey type, size of prey, time since previous meal, size of meal, and number of meals. For striped bass, weakfish, and bluefish, very limited, experimentally derived data on gastric evacuation rates exist (see Hartman, 2000b and Buckel *et al.*, 1999 data on age-0 striped bass and bluefish, respectively). Because basic data to parameterize the simple evacuation rate model across all predator species, size, prey, and temperature combinations are not available, base values for the parameters associated with the exponential decay evacuation rate model (i.e., $\alpha = 0.004$ and $\beta = 0.115$) are obtained from the literature (Durbin *et al.*, 1983). These standard parameters are applied to all species and age classes in the current application

To conduct this sensitivity analysis, changes in the evacuation rate parameter values (α and β) were chosen that allowed for a coarse examination of the effect those changes had on the MSVPA-X. Changes in each of the gut evacuation rate parameters for each predator were conducted to evaluate the importance of impacts on menhaden abundance, biomass, predation mortality, fishing mortality, and consumption outputs in the MSVPA-X. For each predator, four alternate model simulations were performed. Relative to the base value of $\alpha = 0.004$, this parameter was set equal to 0.002 and 0.006, while the parameter β was changed from a base value of $\beta = 0.115$ to 0.05 and 0.20.

D1 1.4.1 Abundance

Changes in the gastric evacuation rate parameter α for each predator has a slight impact on the abundance of age-0 menhaden (Figure D1.27 a.-c.). Decreases in β for each predator causes moderate decreases in age-0 menhaden abundance, while increasing β has little effect on age-0 menhaden abundance (Figure D1.28 a. – c.). The impact of changes to α and β on age-1 menhaden is negligible.

D1 1.4.2 Spawning Stock Biomass

Spawning stock biomass of menhaden is insensitive to selected changes to both α and β .

D1 1.4.3 Predation Mortality (M2)

Changes in predator gut evacuation rate parameters results in changes in both the magnitude and pattern of the M2 estimates from the MSVPA-X. Changes in α for weakfish systematically impact the M2 rates on age-0 and, to a lesser extent, age-1 menhaden, while the M2 rates on older fish are not affected (Figure D1.29a. – b.). Predation mortality of all ages of menhaden is affected by altering the values for α of bluefish, but interestingly the magnitude of the change to M2 on age-0 menhaden is less than on each older age-class (Figure D1.30a. – b.). Changing the α value for striped bass impacts all age-classes, with age-1 menhaden experiencing the greatest divergence in M2 values from the base run (Figure D1.31a. – b.).

Decreasing β for weakfish causes a decrease in M2 for age-0 menhaden, while increasing β results in M2 values similar to the base run for age-0 menhaden (Figure D1.32a.). For age-1 and greater menhaden, M2 is consistently lower than the base run when β is both increased and decreased for weakfish (Figure D1.32b.). Changing β values, either up or down, for bluefish causes M2 of age-0 menhaden to decrease from base run levels (Figure D1.33a.). Decreasing β for bluefish results in lower M2 values on older menhaden, while increasing β generally leads to higher M2 values through the early 1990s and then to M2 rates similar to the base run (Figure D1.33b.). Decreasing β values for striped bass yields lower M2 rates on all ages of menhaden, while increasing β leads to lower M2 rates than the base run until the late 1980s when M2 rates increase to higher levels for all age classes (Figure D1.34a. – b.).

D1 1.4.4 Fishing Mortality

Average recruited fishing mortality on age-2+ menhaden is largely insensitive to changes in the values of α and β .

D1 1.4.5 Consumption

Changing the α parameter for striped bass causes systematic changes in consumption, as both increasing and decreasing α led to an increase and decrease in consumption of the same magnitude (Figure D1.35a. – c.). Consumption of weakfish and bluefish is not affected by changes in α for striped bass (Figures D1.36a. – c and D1.37a. – c.). Changing α for bluefish and weakfish also cause systematic changes in consumption. Notably, striped bass consumption is slightly affected late in the time series (2000-2002), by changes in the α values for weakfish.

Changing β for a single predator species impacts consumption rates for the other two predator species. Reducing β for striped bass results in decreased consumption by both striped bass and bluefish, but weakfish consumption is similar to that of the base run. For weakfish, increasing β does not result in large departures in consumption from the base run, but both striped bass and bluefish consumption are reduced (Figure D1.38 a. – c.) Decreasing β for weakfish leads to lower consumption for all predators. Increasing β for bluefish increases bluefish consumption, but lowers striped bass and weakfish consumption; decreasing β for bluefish reduces consumption for all predators (Figure D1.39a. – c). Increasing β for striped bass leads to increased striped bass consumption, reduced bluefish consumption, and increased consumption by weakfish late in the time series (Figure D1.40a. – c).

D1 1.5 PREY TYPE PREFERENCES

D1 1.5.1 Introduction and Outline of Sensitivity Runs

This section describes a sensitivity analysis examining the ranks for prey preferences used in the base MSVPA-X run. To represent inherent uncertainties in developing ranks for prey preferences, two approaches were developed to explore the sensitivity of MSVPA-X to the base input ranks for prey preferences of the three predator species explicitly modeled (Tables D1.1A-D1.3A). This sensitivity is explored through two alternate simplifications of the base model rank preferences.

The first approach assumes that the ranks for all prey groupings not equal to zero were equally preferred for each predator and age modeled (Tables D1.1B-D1.3B). Four sensitivity MSVPA-X runs were made for this approach: three runs, each modifying just one predator species at a time (e.g., bluefish, weakfish, and striped bass); and one run modifying all three predator species at once. This approach is referred to as all ranks equal, and the short hand reference in the figures in the results section is ‘Equal’.

The second approach distinguishes two major prey groupings: fish and invertebrates. All prey categories within each of these two groups were given equal rank for prey preference (Tables D1.1C-D1.3C). In many instances, rankings of fish and invertebrate prey categories were inter-

mixed. To address that situation for the sensitivity runs, all prey categories of the group (fish or invertebrate) with the top ranking received the highest ranking regardless of initial position. For example, if, for a given predator species and age, benthic crustaceans were initially ranked as 1, clupeids ranked 2, and macroinvertebrates ranked 3, then the final sensitivity rankings would be benthic crustaceans 1.5, macroinvertebrates 1.5 (i.e., all 'invertebrates', reflecting the ranking for two groups tied), and clupeids 3. As with the first approach, four sensitivity MSVPA-X runs were made, first modifying one predator at a time (3 runs) and then modifying all three predators (1 run). This approach is referred to as equal ranks of fish and invertebrates, and the short hand reference in the figures in the results is 'Fish/Invert'.

The remainder of this section describes the results of these sensitivity MSVPA-X runs relative to the results from the base run (described elsewhere, but here implying the initial base rank prey preference matrices for the three predator species). In particular, aspects of menhaden population dynamics (natural and fishing mortality, abundance for ages 0-1, and spawning stock biomass) and predator diet of menhaden (percent diet composition and consumption of menhaden) are explored.

D1 1.5.2 Results of Sensitivity Runs

Annual menhaden M2 at age-0, -1, and -2

M2 is that portion of menhaden natural mortality associated with predation by three predators (bluefish, weakfish and striped bass) explicitly modeled in MSVPA-X. Table D1.4 summarizes annual estimates of M2 on ages 0-2 menhaden for the first approach with all ranks equal, while Table D1.5 summarizes annual estimates of M2 on ages 0-2 menhaden for the second approach with equal ranks for fish and invertebrate.

Although the general pattern of predator mortality on age-0 menhaden (M2 on age-0 menhaden) are similar, estimates of M2 from the base run are highest compared to all ranks equal for one or all of the three predator species (Figure D41). Lowest estimates of M2 on age-0 menhaden are obtained when all ranks equal for all three predators. For a single predator, the lowest estimates are associated with all equal ranks for weakfish. Little difference is noted with all ranks equal for bluefish. Similar patterns are found when equal ranks of fish and invertebrates are assumed (Figure D1.42). The primary difference is a narrowing in differences with the various sensitivity runs for this alternate assumption in rank preferences.

The general pattern and magnitude of predator mortality on age-1 menhaden (M2 on age-1 menhaden) are similar, with estimates of the base run generally intermediate to most of the sensitivity runs for all equal ranks assumed in one or all of the three predator species (Figure D1.43). Highest estimates of M2 on age-1 menhaden are associated with bluefish, and lowest estimates with weakfish when assuming equal rank preference. Similar patterns are also found when equal ranks of fish and invertebrates are assumed (Figure D1.44). Highest estimates of M2 on age-1 menhaden are associated with simplifying rank assumption for bluefish and weakfish, and the lowest values for base, striped bass and all three predators.

Although the general pattern and magnitude of predator mortality on age-2 menhaden (M2 on age-2 menhaden) are similar, the lowest estimates of M2 on age-2 menhaden are associated with the base run, striped bass and weakfish compared to the assumption of all equal ranks for bluefish and all predators (Figure D1.45). Similar results are found when equal ranks of fish and invertebrates are assumed (Figure D1.46).

Annual menhaden average recruited F

Annual estimates of average F (for age-2+ menhaden) are summarized for both alternate approaches to sensitivity in ranking (Table D1.6). Only very minor differences are noted among various runs with the base run for average recruited F (Figures D1.47 and D1.48). Hence, annual estimates of average recruited F appear to be insensitive to errors in rank preferences.

Annual menhaden abundance at age-0 and 1

Annual estimates of abundance of age-0 and age-1 menhaden (in millions of fish) are summarized for all ranks equal (Table D1.7) and for equal ranks of fish and invertebrates (Table D1.8).

Although the general temporal pattern and magnitude of age-0 abundance of menhaden is maintained, there are moderate deviations from the base run when all equal ranks are assumed in one or all of the three predator species (Figure D1.49). Generally the highest estimates are associated with the base run, and lowest estimates associated with equal rank preferences for weakfish all three predators. Similar patterns are also found when equal ranks of fish and invertebrates are assumed, but with intermediate levels for the base run (Figure D1.50).

Only very minor differences are noted among various sensitivity runs for abundance of age-1 menhaden compared to the base run (Figures D1.51 and D1.52). Hence, annual estimates of age-1 menhaden appear to be fairly insensitive to alternative simplification in rank preferences.

Annual menhaden SSB

Annual estimates of menhaden spawning stock biomass (in 1000 mt) are summarized for all ranks equal (Table D1.9) and for equal ranks of fish and invertebrates (Table D1.10). Only very minor differences are noted among the various sensitivity runs compared to the base run for spawning stock biomass (SSB; Figures D1.53 and D1.54). Hence, annual estimates of menhaden SSB appear to be insensitive to alternative simplification of rank preferences.

Percent menhaden in diet composition

Age-specific diet composition of menhaden (percent composition) for the three predator species are summarized by predator age for sensitivity to both alternate ranking approaches (Table D1.11).

Age-specific patterns in diet composition of menhaden in striped bass are presented in Figures D1.55 and D1.56. For the assumption of all equal ranks, all sensitivity runs show a pattern of low

percent of menhaden in diet of young striped bass, and higher percent of menhaden in diet of older striped bass. Diet compositions, when all equal ranks are assumed for striped bass and all three predators, are lower for younger ages of striped bass (age 1-6) and higher for older ages of striped bass (age 9-13), as compared to the base run and assumption of all equal ranks for bluefish and weakfish. This same pattern with age is found also for the assumption of equal ranks for fish and invertebrates.

Regardless of sensitivity run, the pattern is somewhat different for diet composition of menhaden with the shorter-lived (as modeled) weakfish (Figures D1.57 and D1.58). For these sensitivity runs, the base run and both alternate rank preferences for striped bass and bluefish give the highest percent of menhaden in the diet of weakfish. Low percentages are associated with both alternate rank preferences for weakfish and all three predators.

Discerning changes in bluefish diet composition by size class is difficult because only three size classes of bluefish are modeled. Nonetheless, menhaden increase in abundance in bluefish diets as bluefish size increases (Figures D1.59 and D1.60). Similar to the diet compositions of menhaden for striped bass and weakfish, two groupings of similar estimates are found. One group consists of the base run and diet composition estimates with both alternate rank preferences for striped bass and weakfish, and the other group consists of both alternate rank preferences for bluefish and all three predators.

Consumption of menhaden by predators

Consumption of menhaden by predators (biomass, 1000 mt) is summarized for all ranks equal (Table D1.12) and for equal ranks of fish and invertebrates (Table D1.13).

The general pattern and magnitude of menhaden consumption by striped bass are similar among sensitivity runs, with generally increasing consumption of menhaden over time for the base run and sensitivity runs for the assumption of all ranks equal in one or all predator species (Figure D1.61). Low values of menhaden consumption are found with striped bass and all three predators, while higher values are associated with the base run and all ranks equal for weakfish and bluefish. A similar pattern is found when equal ranks for fish and invertebrates are assumed (Figure D1.62).

High menhaden consumption by weakfish is found for the base run and for all equal ranks for striped bass and bluefish (Figure D1.63). Lower values of menhaden consumption are found for all ranks equal for weakfish and for all three predators. A similar pattern is found when equal ranks for fish and invertebrates are assumed (Figure D1.64).

Low values of menhaden consumption by bluefish are found for the base run and for assumed equal rank preferences for striped bass and weakfish (Figure D1.65). Higher values of menhaden consumption are found for all ranks equal for bluefish and for all three predators. A similar pattern is found when equal ranks for fish and invertebrates are assumed (Figure D1.66).

D1 1.5.3 Discussion

The first alternate approach, assuming equal ranks for all positive species groupings, assumes that little is known about prey preference beyond which species groups are preyed upon by a particular age or size group of predator (Table D1.1B-D1.3B). The second alternate approach, separating prey preference into equal ranks for fish and invertebrates, allows for some separation of ranks between these larger groupings (Table D1.1C-D1.1C).

When considering the results of these sensitivity runs, first we investigated different aspects of menhaden population dynamics: annual estimates of natural mortality by predation (ages 0-2), fully recruited fishing mortality (age-2+), and abundance (age-0 and 1, and spawning stock biomass). Natural mortality is split into fixed base natural mortality due to a variety of sources (M1), and that portion of natural mortality that is explicitly considered in this model due to predation by striped bass, weakfish, and bluefish (M2). Specifically, we consider the sensitivity of M2 for ages 0-2 menhaden (Table D1.4-D1.5 and Figures D1.41-D1.46). When comparing M2 among the base run and each of the two alternate simplifying assumptions for rank preference for all three predators, M2 from the base run was highest for age-0, generally intermediate for age-1, and lowest for age-2. On the other hand, average recruited F (ages 2+) for menhaden show very little, if any, sensitivity to the ranks for prey preference (Table D1.6 and Figures D1.47-D1.48).

Menhaden abundance is considered in two ways. First, we estimate abundance in numbers of age-0 and age-1 menhaden, and next we estimate spawning stock biomass (weight of mature female menhaden, SSB). We note some sensitivity in estimating abundance of age-0 menhaden, with the base run providing generally higher estimates than from the two alternate simplifying assumptions for rank preferences for all three predators. However, little sensitivity in abundance is observed for age-1 menhaden (Table D1.7-D1.8 and Figures D1.49-D1.52). Furthermore, there is negligible sensitivity observed in SSB (Table D1.9-D1.10 and Figures D1.53-D1.54). This suggests that we should not expect sensitivity in abundance of menhaden age-3 or older.

Next, we considered the sensitivity in measures of menhaden in the diet of the modeled predators. This aspect was considered in two ways: percent menhaden in the diet composition of the three predators by predator age, and annual estimates of consumption of menhaden biomass in the predator diets (Tables D1.11-D1.13 and Figures D1.55-D1.66). For diet composition and consumption of menhaden, most deviation from the base run is associated with the simplifying rank preference assumption applied to the species considered and all three predators.

D1 1.6 WEIGHT-AT-AGE

This sensitivity analysis examined the effects of changes of constant weight-at-age (based on time series average) and variable weight-at-age (observed data from stock assessment reports) for striped bass and weakfish.

D1 1.6.1 Methods

The weight-at-age matrix for striped bass and weakfish in the base run is based on average values calculated from observed data (1982-2002 for striped bass and 1991-2002 for weakfish) from research studies. In the alternative run, constant weight-at-age tables for striped bass and weakfish were replaced with observed (variable) weight-at-age values (obtained from assessment documents) and its impact on predator total consumption rate, predator consumption of menhaden, and menhaden predation mortality (M2) was evaluated.

D1 1.6.2 Results

Total Consumption Rate:

Total consumption rate for striped bass change little under variable (observed) weight-at-age scenario (Figure D1.67). For weakfish, the variable weight-at-age generates higher total consumption rates during early 1980s, but differences in recent years are not significant (Figure D1.68).

Predator Consumption of Menhaden

Predator consumption of menhaden by striped bass changes little under variable weight-at-age scenario (Figure D1.69). For weakfish, the variable weight-at-age generates higher consumption of menhaden during early 1980s, but differences in recent years are not significant (Figure D1.70).

Predation mortality (M2)

Predation mortality (M2) of menhaden by striped bass calculated based on variable (observed) weight-at-age are similar to those calculated based on constant weight-at-age (Figure D1.71). For weakfish, predation mortality (M2) calculated based on variable weight-at-age is significantly higher during early to mid 1980s and differences are less significant in recent years (Figure D1.72).

D1 1.7 SPATIAL OVERLAP

D1 1.7.1 Introduction and Outline of Spatial Overlap Sensitivity

This series of model runs examined the sensitivity of the MSVPA-X model to changes in the 'Base' spatial overlap values of each predator by age, and their associated prey for all seasons. Spatial overlap values range from 0 (no overlap) to 1 (complete overlap) and therefore, there are thousands of possible spatial overlap combinations for a given predator, prey and seasonal combination. To help simplify the analysis, runs were conducted using spatial overlap values equal to 1 for all species combinations (i.e., all prey for all seasons set equal to 1 for a given predator) and the results were evaluated relative to the 'Base' run (See Table D1.14, S.B. – All, termed Predator Runs). A feature of the MSVPA-X allows the modeler to remove the seasonal aspect of the spatial overlap index if seasonal data is not available or, potentially, if seasonal

aspects or movements are not important. Therefore, sensitivity runs comparing spatial overlap values with seasonality and without seasonality were also investigated (Table D1.14, N.S. 1 and N.S. Ave, termed Seasonal Runs).

D1 1.7.2 Annual Menhaden M2 Results

Menhaden M2 is slightly sensitive to changes in spatial overlap values for the Predator runs and sensitivity tend to decrease with age: age-0 being most sensitive and age-2 being least sensitive (Figures D1.73a – c). Setting the weakfish spatial overlap equal to 1, Weak run, lowers age-0 M2 compared to the Base in almost all years but has little effect on age-1 and age-2 M2. When the bluefish spatial overlap is set equal to 1, Blue run, menhaden M2 increases for all ages in the early part of the time series (1982 – 1987) when bluefish abundance was at its peak; while menhaden M2 increases for all ages in the later part of the time series (1997 – 2002) for the striped bass run, S.B., as the striped bass population recovered.

The Seasonal runs show similar sensitivity trends in that M2 was slightly sensitive to the seasonal aspect of the spatial overlap values, however sensitivity tend to increase with age (Figures D1.74a – c). Seasonal runs tend to be more variable than Predator runs for all age groups and menhaden M2 increased for all age groups compared to the Base. As expected, the All and N.S. 1 runs – all predators' spatial overlap values equal to 1 – produce similar results. The N.S. Ave run, averaging the seasonal spatial overlap values, tend to produce the highest M2 estimates for all ages and is the greatest departure from the Base run estimates. These results emphasize the overall importance and sensitivity of the seasonality aspect incorporated in the model, and the need to accurately describe the movements of the predators in relationship to their prey.

D1 1.7.3 Annual Menhaden Abundance for Ages 0 and 1 Results

Age-0 menhaden total abundance is less sensitive to spatial overlap changes than the age-0 M2 estimates (Figure D1.75a). Also, age-0 abundance trends for a particular model run are what one would expect based on the M2 results – i.e., higher M2 estimates for a particular model run, compared to the Base, produces higher abundance estimates. Age-1 menhaden abundance is not sensitive to changes in spatial overlap values with all Predator runs producing similar results (Figure D1.75b).

Seasonal runs produce similar results as the Predator runs – a slight sensitivity for age-0 abundance, no real sensitivity for age-1 and logical abundance estimates are produced based on the M2 results (Figures D1.76a - b).

D1 1.7.4 Annual Menhaden SSB Results

Menhaden spawning stock biomass estimates are not sensitive to changes in spatial overlap values for either the Predator runs or the Seasonal runs with all runs producing nearly identical results (Figures D1.77a - b). These results are expected since most of the menhaden spawning stock is comprised of 3+ individuals and menhaden predation mortality is predominantly on age

0 – 2. Also, as discussed above, model sensitivity to menhaden predation mortality decreases with age and therefore, has a decreased effect on spawning stock biomass.

D1 1.7.5 Annual Menhaden Average Recruited (2+) F Results

Similar to menhaden spawning stock biomass, annual fully recruited F estimates are not very sensitive to changes in the spatial overlap values for both the Predator and Seasonal runs (Figures D1.78a - b).

D1 1.7.6 Predator Diet Composition Results

Increasing a particular predator's spatial overlap to 1 for all prey and all seasons has a mixed effect on menhaden in the diet when compared to the Base run. For example, menhaden predation (i.e., more menhaden in diet) increases for ages 4 – 8 striped bass and decreases for the other ages, weakfish predation on menhaden is significantly lower for all ages, while bluefish predation increases for middle aged bluefish and decreases for young and old bluefish (Figures D1.80a – c). When all three predators's spatial overlap values are set equal to 1 (All), menhaden predation remains relatively the same in striped bass and bluefish when compared to their specific predator run; while weakfish predation increases slightly compared to the weakfish specific run for all ages but remains below Base run levels (Figure D1.80b).

Changes in diet composition for the other prey types are also highly variable as well as species and age dependent. Clupeids are more abundant in the diet for all ages of striped bass, while medium forage fish and anchovies are much less common (Figures D1.79d and D1.80a). The same pattern is true for bluefish as well (Figures D1.79f and D1.80c). Due to the increase in spatial overlap, clupeids are significantly more common in the diets of weakfish. This result is logical because the clupeid group, largely consisting of Atlantic herring, is found predominantly in New England and the Gulf of Maine where weakfish are not commonly found. Medium forage fish and bay anchovy are more common in the diet of older weakfish and macrozooplankton and benthic invertebrates are much more abundant among all ages (Figures D1.79b and D1.80b). As with menhaden, the diet composition of the other prey types for all three predators remains relatively similar between their predator specific model run and the All predator run, with weakfish the most variable between the runs (Figures D1.79d – f and D1.80a – c).

In predator specific runs (striped bass, weakfish, or bluefish), diet composition only changes in the predator whose spatial overlap is set to 1, the other predators' diets are relatively unaffected (Figures D1.79a – c).

D1 1.7.7 Total Predator Consumption by Prey Type Results

Due to the high sensitivity in the predator diet composition, predator consumption is also highly sensitive to changes in spatial overlap values. Menhaden consumption by striped bass increases from the Base run, as does the associated variability in all years when the striped bass spatial overlap was equal to 1, particularly in the later part of the time series with the increasing and expanding striped bass population (Figure D1.81a). Weakfish consumption of menhaden is the lowest for the weakfish specific run which corresponds to the decrease of menhaden in the diet

for that particular run (Figure D1.81b). Bluefish consumption of menhaden is the greatest for the Blue and All predator runs and the most variable early in the time series when bluefish abundance is high (Figure D1.81c).

Other prey consumption was also highly variable depending upon the prey type and model run but reflected the results observed in the diet composition. For example, there is a substantial increase in clupeid consumption by weakfish in the Weakfish and All predator model runs due to the large increase of clupeids in their diet (Figure D1.81b).

D1 1.8 PREY SIZE PREFERENCE

D1 1.8.1 Background

Prey size-selectivity comprises one component of feeding selectivity in the MSVPA-X and a critical consideration in determining the suitability of prey item are predator-prey length ratios. For a predator of a given length, prey size-selectivity will be dome shaped. For example, prey selected by a predator must fall within a suitable size range that the predator can catch and consume. If a predator can consume a wide variety of prey sizes relative to its own size, the selectivity curve will be ‘flattened’ or ‘squashed’. Predators that have a limited range of suitable prey sizes have a more ‘peaked’ or ‘narrow’ selectivity curve. There is limited data on prey size-selectivity available for the predator species, in particular for weakfish and bluefish. To account for the uncertainty inherent in these data sensitivity analyses were performed to determine the impact of slight changes in the prey size-selectivity curve parameters, directional shifts in median size of prey, and changes in the prey size range consumed by predators.

D1 1.8.2 Methods

The following scenarios were tested to test the sensitivity of the MSVPA-X to various size selectivities. Each scenario was compared to the output from the base run output, and the outputs evaluated were predation mortality (M2) on age-0, 1, and 2 menhaden, the total abundance of age-0 and 1 menhaden, spawning stock biomass of menhaden, and average recruited F on age-2+ menhaden, and predator diet composition and consumption rates. In general, results are reported as percent change from the base run result relative to the change in the input value. Prey size-selectivity parameters can be changed in the MSVPA-X configuration for striped bass and weakfish, but bluefish must be changed in the single-species configuration for each sensitivity run. The values of the size selectivity parameters, α and β , used in the analyses are provided in Tables D1.15 and D1.16.

- 1) Size selectivity parameters (α and β) were adjusted by $\pm 1\%$ for all predators in the model (striped bass, bluefish, and weakfish). The goal of this scenario was to determine if the model is highly sensitive to small changes in α and β values.
- 2) Scenarios were conducted to investigate how shifts in the median prey size-selectivity impact each of the specified outputs above. For all predators combined, shifts in median prey size-selectivity of $\pm 10\%$ and $\pm 20\%$ were investigated. The α and β values were

adjusted using the 'sizesel' macro in Excel that calculates the size selectivity parameters the same way as in the MSVPA-X model.

3) To evaluate the impacts of changes in the range of prey sizes selected by predators, the size ranges or predator-prey size ratios were expanded or contracted by $\pm 10\%$ employing a similar method as in 2. Values for α and β were selected that achieved a 10% expansion and a 10% contraction in the size range of prey selected, while keeping the median size consistent with the base run median size. Striped bass data were available in prey size ranges, but bluefish and weakfish data were presented in terms of predator to prey length ratios; however, the adjustments to the size selectivity curves were performed the same.

D1 1.8.3 Results

1) The MSVPA is robust to 1% changes in the prey size-selectivity curve parameters α and β as these changes slightly altered the output parameters investigated: total, age-0 and age-1 abundance (Table D1.17); spawning stock biomass (Table D1.18), predation mortality (M2) on age-0 and age-1 menhaden (Table D1.19), fishing mortality (Tables D1.20 and D1.21), predator diet composition (Figure D1.82a.-c.), predator consumption rates (Figure D1.83a.-c.).

2) Changes in the median size prey selected by the predators results in expected changes in the output variables observed.

Total, age-0 and age-1 abundance (Figure D1.84 a.-c., Table D1.22)

Decreases in median size of 10% and 20% changes the abundance of age-0, age-1 and total abundance from less than 1% to approximately 10%. Increases in median sizes to 10% and 20% greater than the base run, results in changes in abundance of the same order and in a few cases exceed the change in the input values for α and β . Age-0 abundance is more sensitive than both age-1 and total abundance for each scenario, except the decrease in median prey size by 20%.

Spawning stock biomass (Table D1.23)

Spawning stock abundance is insensitive to changes in median prey size of $\pm 10\%$ and $\pm 20\%$.

Predation mortality (M2) on age-0 and age-1 menhaden (Figure D1.85a.-b., Table D1.24)

Predation mortality estimates behaves expectedly for the given changes in α and β . Note that in the scenarios for age-1 menhaden in which median prey size-selectivity is increased, M2 is substantially higher than the base run and the scenarios where median prey size is decreased.

Fishing mortality (Figure D1.86a.-c., Table D1.25)

Fishing mortality by age and average recruited F are not sensitive to shifts in median prey size.

Predator diet composition & predator consumption rates (Figures D1.82a.-c. and D1.83a.-c.; Table D1.26)

The proportion of menhaden in the diet of the predator species and the consumption of menhaden are the MSVPA-X outputs most affected by changing the median size range of prey selectivity. The changes in proportion of menhaden in each predator diet and the amount of menhaden consumed typically changes relative to the change in median prey size and trends are generally consistent across the scenarios investigated; however, two scenarios affect the proportion of menhaden in the diet of striped bass (Figure D1.826a, the 10% decrease in median prey size and the 20% increase in median prey size).

3) Changes in the range of prey sizes selected by predators, the size ranges

Total, age-0 and age-1 abundance (Figure D1.87)

Abundance of menhaden (age-0, age-1, and total) is insensitive to contractions and expansions in the range of prey size-selectivity for all predators.

Spawning stock biomass (Figure D1.88)

Spawning stock biomass of menhaden was insensitive to contractions and expansions in the range of prey size-selectivity for all predators.

Predation mortality (M2) on age-0 and age-1 menhaden (Table D1.26)

Decreasing the size range of prey selected increases M2 on the smaller and younger menhaden and reduces M2 on older and larger menhaden compared to the base run. Increasing the size range of prey selectivity has the inverse effect.

Fishing mortality (Figure D1.89; Table D1.25)

Neither fishing mortality by age nor average recruited F is sensitive to increases or decreases in prey size-selectivity.

Predator diet composition and predator consumption rates (Figures D1.90a.-c. and D1.91a.-c.)

Estimates and trends in the proportion of menhaden in the diet of the predator species and the consumption of menhaden are predictable and consistent for most of the scenarios tested. For the scenario in which the prey size-selectivity decreased, the largest impact on a predator is for bluefish. In that scenario, consumption of menhaden by bluefish declines substantially; however, total consumption for bluefish of all prey types increases early in the time series, 1982-1990 (Table D1.27). Beginning in 1991, total consumption of bluefish with a decreased size selectivity range is lower than the base run and remains so for the duration of the time series. The total consumption of bluefish in the base run and in the scenario with an increased size range is similar throughout the time series. In addition, the proportion of menhaden consumed declines in the largest size group of bluefish.

D1 2.0 FORECAST PROJECTION RESULTS AND ACCURACY

The MSVPA-X application includes a forecast module that allows exploration of the potential effects of various exploitation patterns, recruitment successes and other “Full MSVPA prey” biomass dynamics. When simulating fishing pressure, the user can enter expected levels of removals in total weight for both prey (menhaden) and predators (striped bass, blue fish, weakfish) or fishing mortality rates for the designated forecast period. Forecasting options for recruitment include several stock-recruitment functions, probability matrices, as well as, the ability to prescribe specific values for each year of the forecast. While these options provide flexibility for future exploration of stock dynamics, it is desirable to test the reliability of model predictions prior to the practical use of the forecasting module.

D1 2.1 FORECAST MODULE ACCURACY

One possible approach to testing the model is to investigate if the forecasting module can reproduce historical observations. To test the ability of the model to reproduce past observations, we used the results of the base run for the 1982 –2002 period. MSVPA-X estimates of population sizes for 1996 were used as a starting point and projections were made for the 1997-2002 period. Estimates of striped bass, weakfish and menhaden recruitment for 1997-2002 from the base run were used as recruitment input for the projection module. Base run estimates of predators fishing mortality rates for the same period served as an input for the forecast module. Fishing pressure on menhaden was simulated in two ways: by entering observed catches for each year of the forecast and by entering “observed” values of fishing mortality (from the “base” run). Projected dynamics of predators and prey were compared with “observed” values from the base run.

Forecasted trends in menhaden total abundance, biomass, spawning stock biomass, predation mortality are similar to those in the base run (Figure 1.92). The forecasted results are not sensitive to the method of fishing removal. Whether the removals are imitated via the total number of fish removed or the fishing mortality applied to the stock, the outputs are very similar, except for the estimate of average recruited F for menhaden. Due to the calculation method used in the forecast module, it is advised to use fishing mortality for the projection rather than absolute catch values. Forecasted and base run values of total absolute abundance and biomass are very close as well. However, there are some differences in the forecasted and “observed” values of menhaden spawning stock biomass (lower values are predicted), predation and fishing mortality (higher predicted values compared to observed for both predation and fishing mortality of menhaden). While the predicted predation mortality on age-0 menhaden does not differ much from the observed, the differences in predicted and observed values of predation on age-1 are more substantial. We were not able to pinpoint the exact reason of such divergence, and further careful analysis is warranted.

D1 2.2 FORECAST MODEL RESULTS

The forecast model is implemented using the base run configuration for the MSVPA-X model with a 5-year projection from 2003-2007. This time frame is chosen based to the potential

limitations of the stock-recruitment relationship for menhaden (Section 2.1). The input for the von Bertalanffy and length-weight relationships for each explicitly modeled species are:

	L_{inf}	K	T_{zero}	L-W α	L-W β
Menhaden	33	0.3737	-0.5642	-10.787	2.9565
Striped Bass	158	0.075	-0.9855	-8.753	2.41222
Weakfish	73.44	0.1745	-0.4719	-6.822	1.7642

The stock-recruitment relationships used in this example projection for each species are: menhaden – random from quartiles, striped bass – Ricker, and weakfish – random from quartiles. Bluefish, and other prey biomasses were assumed to be stable across the projected time frame. Likewise, fishing removals (as F) for all explicitly modeled predators and prey were also assumed constant.

Figure 1.93 (a-c) display the results of the forecast projection for: spawning stock biomass of menhaden, striped bass and weakfish; predation mortality on age-0 through age-4 menhaden; and the amount of menhaden consumed by striped bass, weakfish and bluefish. Overall weakfish and striped bass SSB are expected to decrease over the projected time frame, while menhaden SSB is expected to increase. Predation mortality on ages 1-3 menhaden is simulated to remain fairly constant while predation mortality for age-0 menhaden is projected to decrease slightly. However, the weakfish consumption on menhaden is projected to grow, peaking around 2004.

APPENDIX D1 REFERENCES

- Atlantic States Marine Fisheries Commission (ASMFC). 2003. Stock Assessment Report for Atlantic Striped Bass: Catch-at-Age Based VPA & Tag Release/Recovery Based Survival Estimation. Report# SBTC-2003-3. Washington, D.C.
- Atlantic States Marine Fisheries Commission (ASMFC). 2004. Atlantic Menhaden Stock Assessment Report for Peer Review. ASMFC Stock Assessment Report No. 04-01 (Supplemental). Washington, D.C.
- Buckel, J.A., M.J. Fogarty and D.O. Conover. 1999. Foraging habits of bluefish, *Pomatomus saltatrix*, on the U.S. east coast continental shelf. Fish. Bull. 97: 758-775.
- Durbin, E.G., A.G. Durbin, A.E. Langton and R.E. Bowman. 1983. Stomach contents of silver hake and Atlantic cod and estimation of their daily rations. Fish. Bull. U.S. 81: 437-454.
- Elliot, J.M. and L. Persson. 1978. The estimation of daily rates of food consumption for fish. J. Anim. Ecol. 47: 977-990.
- Hartman, K.J. and S.B. Brandt. 1995. Trophic resource partitioning, diets, and growth of sympatric estuarine predators. Trans. Am. Fish. Soc. 124: 520-537.
- Kahn, D.M. 2002. Stock Assessment of Weakfish through 2000, including estimates of stock size on January 1, 2001. A Report to the Weakfish Technical Committee of the Atlantic States Marine Fisheries Commission.

APPENDIX D1 TABLES

Table D1.1. Base and alternate prey-preference rankings for striped bass in sensitivity MSVPA-X runs.

A. Base	Age 0	Age 1	Age 2	Age 3	Age 4	Age 5	Age 6	Age 7	Age 8	Age 9	Age 10	Age 11	Age 12	Age 13
Striper_2002_13+	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Weakfish_2002	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Menhaden_2002	0	3	3	2	2	2	2	4	4	5	5	5	5	5
Bay Anchovy	0	7	7	6	7	6	5	6	6	6	6	6	6	6
Benthic Crustaceans	0	1	1	4	3	3	3	2	2	2	2	2	2	2
Benthic														
Invertebrates	1	5	5	3	5	5	8	7	7	7	7	7	7	7
Clupeids	0	0	0	0	6	8	7	5	5	4	4	3	3	3
Macrozooplankton	2	6	6	7	8	7	6	0	0	0	0	0	0	0
Medium Forage														
Fish	0	4	4	1	1	1	1	1	1	1	1	1	1	1
Sciaenids	0	2	2	5	4	4	4	3	3	3	3	4	4	4

B. Equal	Age 0	Age 1	Age 2	Age 3	Age 4	Age 5	Age 6	Age 7	Age 8	Age 9	Age 10	Age 11	Age 12	Age 13
Striper_2002_13+	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Weakfish_2002	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Menhaden_2002	0	4	4	4	4.5	4.5	4.5	4	4	4	4	4	4	4
Bay Anchovy	0	4	4	4	4.5	4.5	4.5	4	4	4	4	4	4	4
Benthic Crustaceans	0	4	4	4	4.5	4.5	4.5	4	4	4	4	4	4	4
Benthic														
Invertebrates	1.5	4	4	4	4.5	4.5	4.5	4	4	4	4	4	4	4
Clupeids	0	0	0	0	4.5	4.5	4.5	4	4	4	4	4	4	4
Macrozooplankton	1.5	4	4	4	4.5	4.5	4.5	0	0	0	0	0	0	0
Medium Forage														
Fish	0	4	4	4	4.5	4.5	4.5	4	4	4	4	4	4	4
Sciaenids	0	4	4	4	4.5	4.5	4.5	4	4	4	4	4	4	4

Table D1.1 (Cont'd). Base and alternate prey-preference rankings for striped bass in sensitivity MSVPA-X runs.

C. Fish/Invert	Age 0	Age 1	Age 2	Age 3	Age 4	Age 5	Age 6	Age 7	Age 8	Age 9	Age 10	Age 11	Age 12	Age 13
Striper 2002 13+	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Weakfish 2002	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Menhaden 2002	0	5.5	5.5	2.5	3	3	3	3	3	3	3	3	3	3
Bay Anchovy	0	5.5	5.5	2.5	3	3	3	3	3	3	3	3	3	3
Benthic Crustaceans	0	2	2	6	7	7	7	6.5	6.5	6.5	6.5	6.5	6.5	6.5
Benthic Invertebrates	1.5	2	2	6	7	7	7	6.5	6.5	6.5	6.5	6.5	6.5	6.5
Clupeids	0	0	0	0	3	3	3	3	3	3	3	3	3	3
Macrozooplankton	1.5	2	2	6	7	7	7	0	0	0	0	0	0	0
Medium Forage Fish	0	5.5	5.5	2.5	3	3	3	3	3	3	3	3	3	3
Sciaenids	0	5.5	5.5	2.5	3	3	3	3	3	3	3	3	3	3

Table D1.2. Base and alternate prey-preference rankings for weakfish in sensitivity MSVPA-X runs.

A. Base	Age 0	Age 1	Age 2	Age 3	Age 4	Age 5	Age 6
Striper_2002_13+	0	0	0	0	0	0	0
Weakfish_2002	0	0	0	0	0	0	0
Menhaden_2002	4	1	1	3	3	1	3
Bay Anchovy	3	2	4	6	6	6	5
Benthic Crustaceans	0	6	5	5	4	4	4
Benthic Invertebrates	2	7	6	8	8	8	8
Clupeids	0	0	0	2	2	2	2
Macrozooplankton	1	5	7	7	7	7	7
Medium Forage Fish	0	4	3	4	5	5	6
Sciaenids	0	3	2	1	1	3	1

B. Equal	Age 0	Age 1	Age 2	Age 3	Age 4	Age 5	Age 6
Striper_2002_13+	0	0	0	0	0	0	0
Weakfish_2002	0	0	0	0	0	0	0
Menhaden_2002	2.5	4	4	4.5	4.5	4.5	4.5
Bay Anchovy	2.5	4	4	4.5	4.5	4.5	4.5
Benthic Crustaceans	0	4	4	4.5	4.5	4.5	4.5
Benthic Invertebrates	2.5	4	4	4.5	4.5	4.5	4.5
Clupeids	0	0	0	4.5	4.5	4.5	4.5
Macrozooplankton	2.5	4	4	4.5	4.5	4.5	4.5
Medium Forage Fish	0	4	4	4.5	4.5	4.5	4.5
Sciaenids	0	4	4	4.5	4.5	4.5	4.5

C. Fish/Invert	Age 0	Age 1	Age 2	Age 3	Age 4	Age 5	Age 6
Striper_2002_13+	0	0	0	0	0	0	0
Weakfish_2002	0	0	0	0	0	0	0
Menhaden_2002	3.5	2.5	2.5	3	3	3	3
Bay Anchovy	3.5	2.5	2.5	3	3	3	3
Benthic Crustaceans	0	6	6	7	7	7	7
Benthic Invertebrates	1.5	6	6	7	7	7	7
Clupeids	0	0	0	3	3	3	3
Macrozooplankton	1.5	6	6	7	7	7	7
Medium Forage Fish	0	2.5	2.5	3	3	3	3
Sciaenids	0	2.5	2.5	3	3	3	3

Table D1.3. Base and alternate prey-preference rankings for bluefish in sensitivity MSVPA-X runs.

A. Base	Size 1	Size 2	Size 3
Striper_2002_13+	0	0	0
Weakfish_2002	0	0	0
Menhaden_2002	4	4	5
Bay Anchovy	2	7	6
Benthic Crustaceans	5	6	4
Benthic Invertebrates	6	8	7
Clupeids	7	2	3
Macrozooplankton	8	5	8
Medium Forage Fish	1	1	1
Sciaenids	3	3	2

B. Equal	Size 1	Size 2	Size 3
Striper_2002_13+	0	0	0
Weakfish_2002	0	0	0
Menhaden_2002	4.5	4.5	4.5
Bay Anchovy	4.5	4.5	4.5
Benthic Crustaceans	4.5	4.5	4.5
Benthic Invertebrates	4.5	4.5	4.5
Clupeids	4.5	4.5	4.5
Macrozooplankton	4.5	4.5	4.5
Medium Forage Fish	4.5	4.5	4.5
Sciaenids	4.5	4.5	4.5

C. Fish/Invert	Size 1	Size 2	Size 3
Striper_2002_13+	0	0	0
Weakfish_2002	0	0	0
Menhaden_2002	3	3	3
Bay Anchovy	3	3	3
Benthic Crustaceans	7	7	7
Benthic Invertebrates	7	7	7
Clupeids	3	3	3
Macrozooplankton	7	7	7
Medium Forage Fish	3	3	3
Sciaenids	3	3	3

Table D1.4. Estimates of M2 (age 0-2) for menhaden with equal prey-preference ranking.

	Base			Bluefish			Weakfish			Striped Bass			All Predators		
Year	Age 0	Age 1	Age 2	Age 0	Age 1	Age 2	Age 0	Age 1	Age 2	Age 0	Age 1	Age 2	Age 0	Age 1	Age 2
1982	0.672	0.328	0.207	0.637	0.355	0.256	0.508	0.314	0.206	0.672	0.327	0.207	0.471	0.340	0.256
1983	0.607	0.276	0.171	0.576	0.296	0.211	0.459	0.265	0.170	0.605	0.274	0.171	0.424	0.284	0.211
1984	0.508	0.252	0.168	0.479	0.272	0.206	0.392	0.246	0.168	0.503	0.250	0.168	0.357	0.264	0.206
1985	0.542	0.241	0.164	0.511	0.262	0.203	0.406	0.237	0.164	0.536	0.239	0.163	0.367	0.255	0.204
1986	0.620	0.235	0.158	0.598	0.264	0.200	0.461	0.230	0.158	0.612	0.231	0.158	0.429	0.255	0.199
1987	0.637	0.193	0.119	0.621	0.217	0.149	0.488	0.188	0.119	0.626	0.188	0.118	0.459	0.207	0.148
1988	0.538	0.180	0.099	0.525	0.198	0.123	0.436	0.175	0.099	0.521	0.173	0.098	0.405	0.186	0.121
1989	0.396	0.167	0.093	0.384	0.183	0.114	0.335	0.164	0.093	0.370	0.158	0.091	0.297	0.171	0.112
1990	0.377	0.166	0.093	0.367	0.182	0.113	0.322	0.164	0.094	0.344	0.155	0.091	0.277	0.168	0.111
1991	0.404	0.162	0.087	0.394	0.178	0.105	0.346	0.160	0.087	0.365	0.152	0.086	0.297	0.166	0.104
1992	0.394	0.130	0.062	0.384	0.140	0.073	0.292	0.129	0.062	0.353	0.121	0.061	0.240	0.130	0.073
1993	0.534	0.148	0.068	0.524	0.159	0.080	0.391	0.148	0.068	0.478	0.136	0.068	0.323	0.147	0.080
1994	0.678	0.158	0.068	0.667	0.167	0.078	0.477	0.157	0.068	0.616	0.144	0.068	0.403	0.152	0.078
1995	0.854	0.188	0.072	0.840	0.196	0.083	0.635	0.185	0.072	0.784	0.172	0.072	0.551	0.179	0.083
1996	0.765	0.185	0.063	0.753	0.193	0.072	0.592	0.180	0.063	0.703	0.174	0.064	0.519	0.178	0.073
1997	0.752	0.191	0.060	0.741	0.200	0.068	0.608	0.183	0.059	0.691	0.182	0.061	0.534	0.183	0.069
1998	0.794	0.217	0.070	0.783	0.228	0.080	0.647	0.209	0.070	0.714	0.207	0.072	0.555	0.209	0.082
1999	0.745	0.214	0.073	0.733	0.226	0.085	0.621	0.209	0.073	0.665	0.200	0.074	0.528	0.208	0.086
2000	0.697	0.206	0.077	0.685	0.221	0.091	0.583	0.204	0.078	0.630	0.195	0.079	0.503	0.207	0.092
2001	0.835	0.228	0.090	0.821	0.247	0.107	0.664	0.224	0.090	0.771	0.218	0.092	0.583	0.233	0.109
2002	1.050	0.261	0.109	1.032	0.286	0.130	0.812	0.256	0.109	0.996	0.254	0.112	0.736	0.273	0.133

Table D1.5. Estimates of M2 (age 0-2) for menhaden with fish/invert prey-preference ranking.

Year	Base			Bluefish			Weakfish			Striped Bass			All Predators		
	Age 0	Age 1	Age 2	Age 0	Age 1	Age 2	Age 0	Age 1	Age 2	Age 0	Age 1	Age 2	Age 0	Age 1	Age 2
1982	0.672	0.328	0.207	0.664	0.375	0.267	0.590	0.322	0.207	0.671	0.327	0.208	0.581	0.369	0.268
1983	0.607	0.276	0.171	0.599	0.313	0.218	0.534	0.272	0.171	0.603	0.275	0.171	0.522	0.308	0.218
1984	0.508	0.252	0.168	0.501	0.289	0.214	0.452	0.250	0.168	0.501	0.250	0.168	0.439	0.285	0.215
1985	0.542	0.241	0.164	0.534	0.279	0.211	0.474	0.239	0.164	0.533	0.239	0.164	0.457	0.275	0.211
1986	0.620	0.235	0.158	0.619	0.280	0.208	0.545	0.233	0.158	0.610	0.232	0.158	0.535	0.276	0.208
1987	0.637	0.193	0.119	0.636	0.228	0.154	0.566	0.191	0.119	0.625	0.189	0.118	0.554	0.223	0.155
1988	0.538	0.180	0.099	0.536	0.207	0.128	0.492	0.178	0.099	0.522	0.175	0.099	0.475	0.201	0.127
1989	0.396	0.167	0.093	0.396	0.191	0.118	0.368	0.166	0.093	0.372	0.161	0.092	0.345	0.184	0.118
1990	0.377	0.166	0.093	0.378	0.189	0.117	0.351	0.165	0.093	0.345	0.159	0.093	0.320	0.181	0.116
1991	0.404	0.162	0.087	0.404	0.184	0.108	0.377	0.161	0.087	0.367	0.157	0.088	0.341	0.179	0.109
1992	0.394	0.130	0.062	0.390	0.144	0.075	0.343	0.130	0.062	0.352	0.125	0.063	0.296	0.140	0.077
1993	0.534	0.148	0.068	0.529	0.163	0.082	0.461	0.148	0.068	0.478	0.144	0.070	0.399	0.159	0.084
1994	0.678	0.158	0.068	0.670	0.170	0.080	0.573	0.158	0.068	0.617	0.153	0.070	0.505	0.165	0.082
1995	0.854	0.188	0.072	0.840	0.200	0.084	0.733	0.186	0.072	0.781	0.181	0.076	0.650	0.192	0.088
1996	0.765	0.185	0.063	0.754	0.196	0.073	0.661	0.181	0.063	0.702	0.182	0.066	0.589	0.189	0.077
1997	0.752	0.191	0.060	0.742	0.202	0.070	0.678	0.187	0.060	0.699	0.191	0.063	0.616	0.199	0.073
1998	0.794	0.217	0.070	0.785	0.231	0.081	0.717	0.213	0.070	0.725	0.217	0.075	0.641	0.226	0.086
1999	0.745	0.214	0.073	0.738	0.230	0.086	0.684	0.213	0.073	0.677	0.210	0.077	0.611	0.225	0.090
2000	0.697	0.206	0.077	0.691	0.225	0.093	0.642	0.205	0.078	0.646	0.206	0.082	0.586	0.225	0.097
2001	0.835	0.228	0.090	0.828	0.253	0.110	0.750	0.226	0.090	0.784	0.228	0.095	0.693	0.251	0.114
2002	1.050	0.261	0.109	1.041	0.293	0.134	0.935	0.259	0.109	1.004	0.264	0.115	0.881	0.294	0.140

Table D1.6. Menhaden annual average F (age 2+) with both prey-preference ranking.

Year	Base	Bluefish		Weakfish		Striped Bass		All Predators	
	-	Equal	F&I	Equal	F&I	Equal	F&I	Equal	F&I
1982	1.594	1.546	1.539	1.596	1.594	1.593	1.593	1.547	1.538
1983	1.442	1.407	1.401	1.443	1.442	1.442	1.442	1.407	1.4
1984	1.486	1.448	1.442	1.484	1.486	1.486	1.486	1.448	1.442
1985	1.534	1.492	1.485	1.529	1.534	1.534	1.534	1.491	1.485
1986	1.180	1.148	1.142	1.171	1.180	1.180	1.180	1.147	1.142
1987	1.053	1.032	1.030	1.042	1.053	1.053	1.053	1.032	1.03
1988	1.268	1.249	1.245	1.248	1.268	1.269	1.268	1.245	1.245
1989	1.219	1.201	1.198	1.192	1.219	1.220	1.218	1.195	1.197
1990	1.156	1.141	1.139	1.130	1.156	1.157	1.156	1.135	1.139
1991	1.363	1.351	1.348	1.334	1.363	1.364	1.362	1.337	1.347
1992	1.014	1.006	1.004	0.988	1.014	1.014	1.013	0.992	1.003
1993	1.036	1.027	1.026	1.002	1.036	1.035	1.033	1.011	1.024
1994	0.969	0.963	0.962	0.938	0.969	0.968	0.966	0.948	0.96
1995	1.237	1.231	1.229	1.199	1.237	1.237	1.235	1.207	1.227
1996	0.750	0.746	0.745	0.726	0.750	0.749	0.749	0.730	0.744
1997	0.915	0.911	0.910	0.891	0.915	0.914	0.913	0.892	0.908
1998	1.339	1.332	1.331	1.303	1.339	1.338	1.336	1.308	1.328
1999	1.182	1.174	1.173	1.145	1.182	1.181	1.179	1.153	1.175
2000	0.883	0.876	0.876	0.857	0.883	0.883	0.882	0.860	0.874
2001	1.243	1.235	1.233	1.212	1.243	1.242	1.241	1.212	1.231
2002	1.175	1.168	1.167	1.145	1.175	1.174	1.173	1.148	1.166

Table D1.7. Menhaden abundance at age 0-1 (millions) with equal prey-preference ranking.

	Base		Bluefish		Weakfish		Striped Bass		All Predators	
Year	Age 0	Age 1	Age 0	Age 1	Age 0	Age 1	Age 0	Age 1	Age 0	Age 1
1982	10187.5	8817.3	10190.0	9234.6	8565.8	8696.5	10187.5	8808.0	8309.5	9143.5
1983	15412.0	3413.4	15423.0	3546.7	13331.2	3380.2	15377.7	3411.2	13301.2	3509.8
1984	18489.6	5068.0	18623.2	5253.0	16493.2	5038.0	18352.7	5058.9	16504.3	5217.8
1985	16256.0	6647.8	16484.1	6931.6	14166.3	6621.7	16112.4	6629.3	14243.7	6887.1
1986	12039.3	5937.9	12156.2	6235.7	10188.9	5913.9	11889.3	5924.5	10172.6	6192.0
1987	11209.1	4263.8	11346.1	4420.3	9577.9	4244.0	10956.9	4242.4	9539.6	4379.1
1988	16877.3	3938.7	16985.8	4063.8	15167.0	3920.2	16447.0	3908.1	14941.0	4015.2
1989	6690.1	6374.5	6763.3	6532.8	6267.3	6358.1	6439.5	6317.7	6110.3	6459.2
1990	9613.7	2917.2	9679.1	2988.6	9087.7	2906.5	9228.7	2879.2	8790.2	2946.1
1991	10432.6	4208.9	10478.5	4292.2	9871.6	4202.0	9997.4	4173.1	9505.8	4251.2
1992	9118.2	4094.4	9173.9	4163.9	8266.5	4089.0	8683.5	4065.9	7903.7	4128.6
1993	7338.8	3857.4	7395.8	3925.9	6362.5	3857.4	6894.7	3818.8	5970.5	3884.8
1994	11130.9	2843.4	11163.8	2889.7	9113.9	2841.5	10355.6	2810.1	8453.5	2850.3
1995	7299.2	3728.8	7261.8	3781.1	5793.6	3718.2	6745.1	3682.4	5491.5	3727.6
1996	6800.5	2045.6	6801.4	2073.5	5655.5	2035.1	6358.7	2026.1	5303.4	2046.7
1997	6357.5	2096.7	6375.8	2126.8	5435.6	2081.6	6051.0	2082.0	5100.8	2096.8
1998	8061.8	1990.2	8103.7	2025.0	6921.7	1971.7	7375.7	1971.8	6385.2	1991.1
1999	6265.4	2395.8	6343.4	2447.2	5531.2	2383.2	5750.0	2369.9	5135.1	2410.6
2000	3806.0	1884.5	3865.4	1938.7	3387.3	1880.1	3535.8	1868.2	3198.8	1915.9
2001	7725.9	1224.4	7805.6	1263.6	6552.3	1220.7	7230.7	1214.0	6127.2	1247.7
2002	9427.0	2228.8	9657.2	2289.2	8045.1	2242.1	8939.1	2222.0	7566.3	2277.3

Table D1.8. Menhaden abundance at age 0-1 (millions) with fish/invert prey-preference ranking.

Year	Base		Bluefish		Weakfish		Striped Bass		All Predators	
	Age 0	Age 1	Age 0	Age 1	Age 0	Age 1	Age 0	Age 1	Age 0	Age 1
1982	10187.5	8817.3	10672.2	9452.3	9354.3	8768.9	10173.9	8808.0	9793.4	9402.4
1983	15412.0	3413.4	16066.5	3614.7	14359.3	3400.7	15368.1	3411.2	14874.9	3600.2
1984	18489.6	5068.0	19386.0	5348.6	17483.4	5054.7	18309.0	5059.7	18235.4	5330.4
1985	16256.0	6647.8	17194.8	7068.8	15182.9	6630.7	16075.5	6630.7	15921.0	7047.7
1986	12039.3	5937.9	12587.3	6359.8	11061.9	5932.8	11862.5	5926.7	11531.2	6348.7
1987	11209.1	4263.8	11607.4	4481.7	10418.7	4255.3	11043.6	4251.7	10719.7	4457.9
1988	16877.3	3938.7	17360.2	4108.1	16232.9	3929.9	16526.7	3919.2	16249.7	4084.0
1989	6690.1	6374.5	6905.5	6591.9	6498.5	6369.0	6488.1	6339.9	6518.7	6550.3
1990	9613.7	2917.2	9848.0	3013.3	9366.6	2912.2	9290.0	2894.4	9277.7	2991.4
1991	10432.6	4208.9	10638.7	4318.8	10171.7	4208.9	10077.9	4195.8	10005.8	4305.7
1992	9118.2	4094.4	9317.8	4186.8	8671.7	4094.4	8745.4	4090.0	8465.0	4174.8
1993	7338.8	3857.4	7467.5	3963.6	6837.6	3857.4	6945.2	3852.1	6298.5	3939.7
1994	11130.9	2843.4	11244.2	2901.7	10007.8	2843.4	10457.2	2837.5	9508.7	2894.8
1995	7299.2	3728.8	7302.8	3797.7	6433.9	3725.3	6786.3	3719.3	6032.6	3783.8
1996	6800.5	2045.6	6875.1	2084.0	6113.2	2037.0	6390.6	2043.9	5795.2	2073.5
1997	6357.5	2096.7	6420.3	2133.5	5880.3	2090.5	6056.6	2104.5	5643.7	2132.5
1998	8061.8	1990.2	8165.2	2032.5	7455.1	1980.9	7535.2	1993.3	7121.6	2023.8
1999	6265.4	2395.8	6410.4	2460.2	5898.4	2393.6	5891.4	2396.1	5694.8	2458.8
2000	3806.0	1884.5	3920.4	1949.9	3591.8	1884.5	3637.2	1891.3	3546.5	1956.2
2001	7725.9	1224.4	7870.2	1274.0	7073.8	1221.6	7381.4	1228.2	6971.4	1274.6
2002	9427.0	2228.8	9708.9	2297.1	8720.7	2226.8	9115.8	2230.7	8538.6	2316.2

Table D1.9. Menhaden spawning stock biomass (1000 mt) with equal prey-preference ranking.

Year	Base	Bluefish	Weakfish	Striped Bass	All Predators
1982	86.3	88.6	86.3	86.4	88.6
1983	68.7	70.5	68.7	68.7	70.5
1984	92.9	94.3	92.9	93.0	94.3
1985	52.3	53.3	52.3	52.3	53.4
1986	55.6	57.0	55.6	55.6	57.0
1987	107.6	109.8	107.6	107.6	109.8
1988	142.1	143.8	142.1	142.1	143.8
1989	111.2	112.6	111.2	111.2	112.6
1990	117.5	118.9	117.5	117.5	118.9
1991	127.7	128.8	127.7	127.7	128.8
1992	81.0	81.5	81.0	81.0	81.5
1993	80.8	81.3	80.8	80.8	81.4
1994	102.2	102.9	102.2	102.4	102.9
1995	101.4	101.8	101.4	101.4	101.9
1996	70.8	71.2	70.8	70.8	71.2
1997	181.7	182.4	181.8	181.8	182.5
1998	161.1	161.6	161.1	161.2	161.7
1999	89.0	89.4	89.0	89.0	89.4
2000	77.8	78.2	77.8	77.8	78.3
2001	101.4	102.0	101.4	101.5	102.1
2002	79.6	80.1	79.6	79.7	80.2

Table D1.10. Menhaden spawning stock biomass (1000 mt) with fish/invert prey-preference ranking.

<i>Year</i>	Base	Bluefish	Weakfish	Striped Bass	All Predators
1982	86.3	88.9	86.3	86.4	89.0
1983	68.7	70.7	68.7	68.7	70.8
1984	92.9	94.5	92.9	93.0	94.5
1985	52.3	53.5	52.3	52.3	53.5
1986	55.6	57.2	55.6	55.6	57.3
1987	107.6	110.2	107.6	107.6	110.2
1988	142.1	144.1	142.1	142.1	144.1
1989	111.2	112.8	111.2	111.3	112.8
1990	117.5	119.1	117.5	117.6	119.2
1991	127.7	128.9	127.7	127.8	129.0
1992	81.0	81.6	81.0	81.1	81.6
1993	80.8	81.4	80.8	80.9	81.5
1994	102.2	103.0	102.2	102.5	103.1
1995	101.4	101.9	101.4	101.5	102.1
1996	70.8	71.3	70.8	70.9	71.4
1997	181.7	182.6	181.8	181.9	182.7
1998	161.1	161.6	161.1	161.3	161.8
1999	89.0	89.4	89.0	89.1	89.5
2000	77.8	78.3	77.8	77.9	78.4
2001	101.4	102.1	101.4	101.5	102.3
2002	79.6	80.2	79.6	79.7	80.4

Table D1.11. Diet composition of menhaden (%) for each predator age.

Striped Bass									
<i>When modifying:</i>		Bluefish		Weakfish		Striped Bass		All Predators	
Age Class	Base	Equal	F/I	Equal	F/I	Equal	F/I	Equal	F/I
Age 0	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Age 1	2.4%	2.4%	2.5%	2.2%	2.3%	1.1%	0.6%	1.1%	0.6%
Age 2	8.4%	8.5%	8.6%	8.0%	8.2%	4.1%	2.2%	4.0%	2.2%
Age 3	8.7%	8.8%	8.9%	8.4%	8.5%	5.1%	2.7%	5.0%	2.8%
Age 4	11.2%	11.4%	11.5%	10.9%	11.1%	5.2%	9.4%	5.1%	9.5%
Age 5	28.1%	28.5%	28.6%	27.5%	27.8%	18.4%	21.4%	18.2%	21.6%
Age 6	29.7%	30.1%	30.3%	29.3%	29.5%	19.8%	22.1%	19.7%	22.4%
Age 7	28.2%	28.6%	28.8%	27.9%	28.1%	25.7%	28.6%	25.8%	29.0%
Age 8	28.9%	29.3%	29.5%	28.7%	28.8%	27.0%	29.7%	27.2%	30.1%
Age 9	31.1%	31.5%	31.6%	30.9%	31.0%	38.2%	41.3%	38.4%	41.8%
Age 10	35.8%	36.2%	36.3%	35.8%	35.8%	44.7%	47.2%	45.0%	47.7%
Age 11	31.3%	31.6%	31.7%	31.2%	31.2%	41.0%	43.0%	41.3%	43.4%
Age 12	29.3%	29.6%	29.7%	29.2%	29.3%	38.8%	40.5%	39.1%	40.9%
Age 13	29.1%	29.4%	29.5%	29.1%	29.1%	38.4%	39.9%	38.7%	40.2%

Weakfish									
<i>When modifying:</i>		Bluefish		Weakfish		Striped Bass		All Predators	
Age Class	Base	Equal	F/I	Equal	F/I	Equal	F/I	Equal	F/I
Age 0	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Age 1	4.0%	4.0%	4.1%	1.0%	2.4%	3.9%	3.9%	1.0%	2.3%
Age 2	26.9%	27.1%	27.4%	13.8%	20.7%	26.5%	26.6%	13.5%	20.7%
Age 3	41.5%	41.8%	42.1%	27.2%	33.8%	41.0%	41.2%	27.0%	33.9%
Age 4	48.9%	49.4%	49.6%	37.5%	43.3%	48.5%	48.7%	37.5%	43.7%
Age 5	53.9%	54.3%	54.5%	38.8%	43.9%	53.5%	53.7%	38.9%	44.3%
Age 6	47.7%	48.2%	48.3%	42.1%	46.6%	47.5%	47.6%	42.2%	47.1%

Bluefish									
<i>When modifying:</i>		Bluefish		Weakfish		Striped Bass		All Predators	
Age Class	Base	Equal	F/I	Equal	F/I	Equal	F/I	Equal	F/I
Size 1	3.1%	1.7%	4.4%	2.8%	2.9%	3.0%	3.0%	1.5%	4.1%
Size 2	29.7%	24.7%	29.8%	29.1%	29.4%	29.4%	29.5%	23.9%	29.3%
Size 3	29.0%	36.7%	38.0%	29.0%	29.0%	29.0%	29.0%	36.5%	37.9%

Table D1.12. Consumption of menhaden (1000 mt) by predators for equal prey-preference ranking.

<i>When modifying:</i>															
	Base			Bluefish			Weakfish			Striped Bass			All Predators		
Year	SB	WF	BF	SB	WF	BF	SB	WF	BF	SB	WF	BF	SB	WF	BF
1982	6.9	80.0	160.7	7.1	81.2	183.3	6.8	52.4	158.8	5.3	80.8	161.1	5.3	53.1	181.6
1983	6.2	74.6	107.5	6.3	75.3	118.2	6.0	44.7	105.6	4.3	75.3	107.7	4.3	45.5	116.7
1984	8.4	68.7	107.0	8.6	69.6	112.9	8.2	41.2	105.4	5.6	69.1	107.1	5.6	41.9	111.5
1985	10.6	65.8	120.2	10.9	67.2	129.9	10.4	36.9	118.5	7.2	66.1	120.3	7.3	37.8	128.3
1986	16.7	85.3	160.1	17.1	86.4	183.6	16.2	48.2	157.5	11.2	85.4	160.0	11.2	49.0	181.1
1987	20.6	98.9	123.8	21.0	100.1	143.4	20.0	60.0	121.7	14.3	98.4	123.3	14.2	60.7	141.2
1988	34.2	122.9	102.5	34.6	123.5	113.7	33.4	82.2	100.9	22.6	122.2	101.9	22.4	82.3	111.6
1989	34.6	38.5	85.4	35.0	38.8	98.9	34.5	27.2	85.2	24.7	38.1	84.9	24.9	27.2	98.2
1990	42.4	37.3	70.6	42.8	37.4	80.0	42.1	24.7	70.3	29.9	36.7	70.0	30.0	24.4	79.2
1991	45.0	35.9	56.9	45.2	36.0	64.6	44.7	24.2	56.7	33.3	35.4	56.5	33.3	23.8	64.0
1992	39.7	26.9	34.8	40.0	27.0	39.5	39.3	14.8	34.6	29.6	26.4	34.6	29.4	14.6	39.2
1993	47.2	30.8	33.8	47.5	31.0	39.3	46.4	16.5	33.6	36.1	30.0	33.6	35.7	16.0	38.9
1994	58.0	60.1	29.4	58.3	60.2	33.3	56.1	30.4	28.9	43.0	57.9	29.1	41.8	29.3	32.6
1995	54.1	57.3	26.5	54.2	57.0	30.8	52.4	33.3	26.2	41.9	55.4	26.3	41.3	32.9	30.4
1996	65.0	85.6	29.7	65.1	85.3	34.4	62.6	52.5	29.2	50.1	83.2	29.5	48.7	51.1	33.7
1997	64.8	83.5	29.9	65.0	83.3	34.6	62.7	55.6	29.4	50.7	82.7	29.8	49.0	54.1	33.9
1998	86.7	97.0	33.4	87.3	97.1	37.9	83.7	62.7	32.7	64.9	93.1	32.9	63.4	60.6	36.8
1999	80.2	68.5	36.8	81.2	69.1	42.6	78.6	46.4	36.3	61.1	66.0	36.4	60.6	45.2	41.7
2000	56.6	38.7	37.1	57.4	39.2	44.4	55.8	26.2	36.8	46.0	37.6	36.8	46.1	25.8	43.9
2001	70.7	84.8	46.7	71.6	85.6	52.9	68.4	51.0	45.7	54.3	82.4	46.2	53.1	49.4	51.3
2002	79.2	134.2	69.2	81.0	137.6	78.5	79.3	83.6	69.3	63.1	131.7	68.8	63.2	81.4	77.0

Table D1.13. Consumption of menhaden (1000 mt) by predators for fish/invert prey-preference ranking.

<i>When modifying:</i>															
	Base			Bluefish			Weakfish			Striped Bass			All Predators		
Year	SB	WF	BF	SB	WF	BF	SB	WF	BF	SB	WF	BF	SB	WF	BF
1982	6.9	80.0	160.7	7.2	82.8	200.7	6.8	65.5	159.9	5.7	80.6	160.9	5.9	68.3	200.0
1983	6.2	74.6	107.5	6.4	76.9	129.4	6.1	58.6	106.6	4.4	75.1	107.6	4.5	60.7	128.5
1984	8.4	68.7	107.0	8.8	71.1	125.7	8.3	54.3	106.2	5.4	68.8	106.9	5.6	56.5	124.9
1985	10.6	65.8	120.2	11.1	68.8	143.8	10.5	50.1	119.4	7.0	65.9	120.1	7.2	52.4	142.9
1986	16.7	85.3	160.1	17.3	87.9	200.8	16.4	65.3	158.6	11.7	85.1	159.7	12.1	67.9	199.6
1987	20.6	98.9	123.8	21.2	100.9	155.2	20.4	78.4	122.9	15.4	98.8	123.6	15.6	80.5	154.1
1988	34.2	122.9	102.5	34.9	124.4	124.1	34.1	103.4	102.2	24.8	122.3	102.1	25.1	103.7	123.0
1989	34.6	38.5	85.4	35.2	39.0	106.6	34.6	33.0	85.3	27.1	38.2	85.0	27.6	33.2	106.2
1990	42.4	37.3	70.6	43.0	37.6	86.3	42.3	30.7	70.5	31.9	36.9	70.2	32.3	30.6	85.9
1991	45.0	35.9	56.9	45.4	36.0	69.9	44.9	30.1	56.9	35.9	35.6	56.7	36.2	29.9	69.5
1992	39.7	26.9	34.8	40.2	27.2	42.5	39.5	20.1	34.7	31.3	26.5	34.7	31.4	20.0	42.3
1993	47.2	30.8	33.8	47.7	31.0	42.2	46.8	22.7	33.7	39.0	30.1	33.7	38.5	21.4	41.6
1994	58.0	60.1	29.4	58.3	60.1	35.8	56.9	42.6	29.1	46.0	58.3	29.2	45.5	41.5	35.3
1995	54.1	57.3	26.5	54.2	56.7	33.0	53.2	42.7	26.3	44.9	55.6	26.4	44.5	41.3	32.7
1996	65.0	85.6	29.7	65.3	85.2	36.8	63.6	64.3	29.4	52.8	83.5	29.6	52.1	62.4	36.3
1997	64.8	83.5	29.9	65.1	83.0	37.0	63.7	67.7	29.6	55.3	82.3	29.8	54.7	66.1	36.6
1998	86.7	97.0	33.4	87.4	96.9	40.8	85.2	77.2	33.0	70.9	94.4	33.1	70.5	75.6	40.2
1999	80.2	68.5	36.8	81.4	69.1	45.7	79.5	56.8	36.6	67.3	67.1	36.6	67.7	56.2	45.3
2000	56.6	38.7	37.1	57.6	39.3	47.3	56.2	32.0	36.9	51.5	38.3	37.0	52.0	32.1	47.2
2001	70.7	84.8	46.7	71.6	85.3	57.0	69.2	65.5	46.0	59.7	83.4	46.5	59.8	65.6	56.3
2002	79.2	134.2	69.2	80.6	136.5	84.4	79.1	106.8	69.1	68.7	133.3	69.1	69.4	106.2	84.0

Table D1.14. Summary of the Spatial Overlap sensitivity runs – model run name and a brief description. Refer to table when looking at figures below. Areas highlighted in grey are referred to as ‘Predator Runs’ and those in yellow are ‘Seasonal Runs’. * Description of how original ‘Base’ run spatial overlap values were developed is described in document.

Model Run Name	Spatial Overlap Description/Combination
Base	Original spatial overlap values *
Ex 1	Striped Bass values = 1 for all prey and seasons Other predators same as Base
Ex 2	Weakfish values = 1 for all prey and seasons Other predators same as Base
Ex 3	Bluefish values = 1 for all prey and seasons Other predators same as Base
Ex 4	All Predators = 1 for all prey and seasons
Ex 5	All Predators = 1 for all prey and NO seasons Compared to Ex 4
Ex 6	Average seasonal values for All predators and NO seasons . Compared to Base

Table D1.15. Values of the prey size selectivity curve parameters, α and β , for the base run and sensitivity analyses scenarios 1) Is the MSVPA highly sensitive to the values selected for α and β ($\pm 1\%$ change in the parameters), and 2) How sensitive is the MSVPA to shifts in median size of animals consumed.

	Base Run		-1% Change in α and β		+1% Change in α and β		-10% Shift in median size		+10% Shift in median size		-20% Shift in median size		+20% Shift in median size	
Size Selectivity Parameters	α	β	α	β	α	β	α	β	α	β	α	β	α	β
Age 0-4 Striped Bass	2.98	11.244	2.9502	11.13156	3.0098	11.35644	2.7	10.8	3.3	11.6	2.37	11.6	3.7	12.15
Age 5-9 Striped Bass	9.1	35.2	9.009	34.848	9.191	35.552	8.05	30	10.72	32	6.75	28.4	12.3	33
Age 10+ Striped Bass	13.9	51.2	13.761	50.688	14.039	51.712	8.65	50	16	53	10.6	48	19.5	25
Weakfish	10.1	25.5	9.999	25.245	9.191	35.552	8.65	25	11.1	25	7.5	24.5	12.5	25
Bluefish	10.1	25.5	9.999	25.245	9.191	35.552	8.65	25	11.1	25	7.5	24.5	12.5	25

Table D1.16. Values of the prey size selectivity curve parameters, α and β , for the scenarios with a change in prey size range compared to the base run to test the sensitivity of the model to dramatically different prey size selectivity curves.

	Base Run		Decrease in prey size range (10%)		Increase in prey size range (10%)	
Size Selectivity Parameters	α	β	α	β	α	β
Age 0-4 Striped Bass	2.98	11.244	6.85	31	2.55	9
Age 5-9 Striped Bass	9.1	35.2	20.2	82	6.7	25
Age 10+ Striped Bass	13.9	51.2	33	130	12.1	44
Weakfish	10.1	25.5	27.2	72	8	20
Bluefish	10.1	25.5	27.2	72	8	20

Table D1.17. Percent change in abundance (numbers) of age-0, age-1 and total abundance of menhaden given a $\pm 1\%$ change in the prey size selectivity curve parameters α & β from the base run condition for all predators combined (striped bass, weakfish and bluefish) in the MSVPA-X.

Year	-1% change in α & β			+1% change in α & β		
	Age 0	Age 1	Total	Age 0	Age 1	Total
1982	0.287	0.105	0.172	0.287	0.105	0.173
1983	0.041	0.000	0.028	0.041	0.000	0.029
1984	0.270	0.079	0.209	0.262	0.079	0.205
1985	0.292	0.086	0.211	0.233	0.056	0.165
1986	0.365	0.093	0.235	0.365	0.025	0.210
1987	-0.224	0.000	-0.123	0.160	0.000	0.096
1988	0.248	0.000	0.177	0.350	0.109	0.269
1989	0.312	0.041	0.151	0.043	0.044	0.036
1990	0.062	0.171	0.080	0.000	0.000	0.010
1991	0.101	-0.005	0.061	-0.090	0.000	-0.056
1992	-0.027	0.000	-0.017	-0.013	-0.110	-0.038
1993	-0.354	0.000	-0.192	-0.132	-0.029	-0.097
1994	0.119	-0.127	0.058	0.113	0.035	0.072
1995	0.256	0.000	0.136	0.864	0.094	0.509
1996	0.290	-0.044	0.171	0.209	0.112	0.151
1997	-4.400	-0.105	-2.783	0.171	0.000	0.116
1998	0.394	-0.075	0.261	0.175	0.085	0.137
1999	0.313	0.008	0.193	0.000	0.054	0.013
2000	0.247	-0.005	0.129	0.097	0.000	0.063
2001	0.841	-0.016	0.629	-0.326	0.000	-0.244
2002	0.152	0.000	0.111	0.075	0.045	0.065

Table D1.18. Spawning stock biomass (SSB) in thousands of metric tons of menhaden from the base run MSVPA configuration and the SSB of menhaden a ± 1 percent change in the prey size selectivity curves α & β .

Base Run SSB	SSB with a -1% change in α & β	SSB with a +1% change in α & β
86.31	86.31	86.3
68.73	68.73	68.72
92.93	92.98	92.93
52.3	52.3	52.27
55.58	55.58	55.58
107.6	107.58	107.58
142.1	142.09	142.07
111.24	111.24	111.23
117.54	117.53	117.53
127.72	127.72	127.72
81.02	81.02	81.02
80.75	80.76	80.77
102.24	102.25	102.38
101.38	101.39	101.38
70.78	70.78	70.77
181.74	181.75	181.67
161.14	161.15	161.14
89	89.01	89
77.76	77.79	77.74
101.38	101.38	101.38
79.57	79.59	79.57

Table D1.19. Change in predation mortality (M2) for age-0 and age-1 menhaden from the base run when the size selectivity curve parameters (α & β) in the MSVPA-X are changed by ± 1 percent.

Year	Age 0			Age 1		
	Base Run M2 Rates by Year	Change in M2 from Base Run		Base Run M2 Rates by Year	Change in M2 from Base Run	
		-1% Change in α & β	+1% Change in α & β		-1% Change in α & β	+1% Change in α & β
1982	0.672	-0.002	0.003	0.328	-0.001	0
1983	0.607	-0.002	0.002	0.276	0	0
1984	0.508	-0.001	0.002	0.252	0	0
1985	0.542	-0.001	0.002	0.241	0	0
1986	0.62	-0.002	0.002	0.235	0	0
1987	0.637	-0.002	0.002	0.193	0	0
1988	0.538	-0.002	0.002	0.18	0	0
1989	0.396	-0.002	0.001	0.167	0	0
1990	0.377	-0.001	0.002	0.166	0	-0.001
1991	0.404	-0.002	0.001	0.162	0	0
1992	0.394	-0.001	0.002	0.13	-0.001	0
1993	0.534	-0.002	0.002	0.148	0	0
1994	0.678	-0.003	0.003	0.158	0	0
1995	0.854	-0.003	0.003	0.188	0	0.001
1996	0.765	-0.003	0.002	0.185	0	0
1997	0.752	-0.001	0.003	0.191	0.001	0
1998	0.794	-0.004	0.004	0.217	0	0
1999	0.745	-0.004	0.004	0.214	0	0
2000	0.697	-0.003	0.003	0.206	0	0
2001	0.835	-0.004	0.004	0.228	0	0
2002	1.05	-0.004	0.005	0.261	0	-0.001

Table D1.20. Change in fishing mortality (F) for age-0 and age-1 menhaden from the base run when the size selectivity curve parameters (α & β) in the MSVPA-X are changed by ± 1 percent.

Year	Age 0			Age 1		
	Base Run F Rates by Year	Change in F from Base Run		Base Run F Rates by Year	Change in F from Base Run	
		-1% Change in α & β	+1% Change in α & β		-1% Change in α & β	+1% Change in α & β
1982	0.018	0	0	0.157	0	0
1983	0.104	0	0	0.23	0	0
1984	0.112	0	0	0.316	0	0
1985	0.062	0	0	0.247	0	0
1986	0.013	0	0	0.055	0	0
1987	0.006	0	0	0.174	0	0
1988	0.031	0	0.001	0.104	0	0
1989	0.033	0	0	0.272	0	0
1990	0.047	0	0	0.071	0	0
1991	0.13	0	0	0.387	0	0
1992	0.065	0	0	0.263	0	0
1993	0.014	0	0	0.14	0	0
1994	0.013	0	0	0.141	0	0
1995	0.014	0	0	0.218	0	0.001
1996	0.008	0	0	0.146	0	0
1997	0.007	-0.001	0	0.172	-0.001	0
1998	0.016	0	0	0.135	0	0
1999	0.053	0	0	0.185	0	0
2000	0.034	0	0	0.094	0	0
2001	0.005	0	0	0.052	0	0
2002	0.036	0	0	0.141	0	0

Table D1.21. Average recruited fishing mortality on age-2 and older menhaden for the base run and for $\pm 1\%$ changes in the size selectivity curve parameters α and β .

Year	Average Recruited F		
	Base Run	-1% change in α and β	+1% change in α and β
1982	1.594	1.594	1.594
1983	1.442	1.442	1.442
1984	1.486	1.486	1.486
1985	1.534	1.534	1.534
1986	1.18	1.18	1.18
1987	1.053	1.053	1.053
1988	1.268	1.268	1.269
1989	1.219	1.219	1.219
1990	1.156	1.156	1.156
1991	1.363	1.363	1.363
1992	1.014	1.014	1.014
1993	1.036	1.036	1.035
1994	0.969	0.969	0.968
1995	1.237	1.237	1.237
1996	0.75	0.75	0.75
1997	0.915	0.915	0.915
1998	1.339	1.338	1.339
1999	1.182	1.181	1.182
2000	0.883	0.883	0.883
2001	1.243	1.243	1.243
2002	1.175	1.174	1.175

Table D1.22. Percent change from base run MSVPA-X abundance results for age-0, age-1 and total abundance of menhaden for sensitivity analysis scenarios in which the median size of prey selected for each predator was shifted by $\pm 10\%$ and $\pm 20\%$.

	Percent Change from Base Run Results for age-0, age-1, and Total Menhaden Abundance											
	10% Decrease in Median Prey Size			10% Increase in Median Prey Size			20% Decrease in Median Prey Size			20% Increase in Median Prey Size		
Year	Age 0	Age 1	Total	Age 0	Age 1	Total	Age 0	Age 1	Total	Age 0	Age 1	Total
1982	3.989	1.955	2.934	-13.352	-7.949	-9.226	-4.663	0.915	-1.539	-21.181	-13.486	-15.136
1983	3.504	1.178	2.831	-10.646	-7.093	-8.320	-3.576	0.756	-2.082	-16.957	-11.880	-13.469
1984	2.895	0.985	2.436	-10.696	-5.649	-8.825	-1.997	1.569	-1.024	-17.756	-9.382	-14.717
1985	6.188	0.719	4.340	-14.567	-5.939	-11.012	-4.879	2.162	-2.464	-27.462	-9.814	-20.458
1986	9.196	2.046	6.179	-15.529	-5.824	-10.520	-6.550	2.253	-2.854	-30.617	-10.253	-20.543
1987	11.338	2.451	7.622	-16.989	-5.134	-11.149	-6.693	1.485	-3.320	-31.819	-10.033	-21.149
1988	6.758	2.628	5.457	-9.507	-5.728	-7.771	-0.410	1.262	0.053	-15.002	-10.816	-12.655
1989	4.517	1.773	2.902	-7.991	-5.244	-5.664	2.984	1.997	2.286	-12.740	-8.889	-9.375
1990	4.551	2.002	3.414	-7.171	-5.570	-5.577	2.326	3.003	2.225	-13.382	-9.454	-10.325
1991	4.496	1.587	3.318	-6.943	-4.778	-5.581	2.567	2.336	2.295	-11.743	-7.921	-9.482
1992	5.349	1.497	3.753	-9.036	-5.065	-6.903	2.365	2.489	2.223	-15.165	-8.028	-11.554
1993	6.174	1.807	4.040	-11.610	-6.828	-8.520	1.649	3.417	2.048	-20.563	-10.357	-14.657
1994	10.796	2.149	7.825	-13.192	-8.279	-10.630	-0.985	3.285	0.086	-26.139	-13.368	-20.552
1995	9.855	2.481	6.362	-6.628	-8.949	-6.561	3.296	2.419	2.697	-13.027	-15.477	-12.369
1996	7.394	3.143	5.421	-7.689	-8.951	-6.855	3.845	1.755	2.938	-14.039	-16.108	-12.709
1997	8.186	3.730	6.089	-10.284	-9.205	-8.621	5.850	1.111	4.058	-17.499	-16.125	-15.101
1998	8.627	3.889	6.821	-10.230	-11.366	-9.291	7.327	2.040	5.568	-16.334	-19.099	-15.264
1999	8.426	3.740	6.394	-9.471	-11.178	-8.952	7.138	3.114	5.404	-15.646	-18.804	-15.067
2000	8.290	3.757	5.814	-10.533	-10.597	-8.960	5.483	3.805	4.275	-18.290	-17.808	-15.681
2001	10.419	3.953	8.511	-13.154	-11.173	-11.446	4.204	3.839	3.801	-23.222	-18.564	-20.254
2002	8.806	2.786	7.204	-12.641	-9.947	-11.339	1.650	3.343	1.926	-20.814	-16.013	-18.731

Table D1.23. Percent change in menhaden spawning stock biomass from MSVPA-X base run configuration and for four scenarios in which the median size of prey selected for each predator was shifted by $\pm 10\%$ and $\pm 20\%$.

Year	Percent Change in Spawning Stock Biomass from MSVPA-X Base Run Configuration			
	10% Decrease in Median Prey Size	10% Increase in Median Prey Size	20% Median Decrease in Median Prey Size	20% Median Increase in Median Prey Size
1982	2.61	0.94	1.56	0.32
1983	2.27	0.58	1.43	-0.06
1984	1.83	0.96	1.07	0.62
1985	1.89	0.75	1.20	0.31
1986	2.54	0.95	1.66	0.31
1987	2.27	0.70	1.55	0.05
1988	1.44	0.40	0.96	-0.18
1989	1.50	0.22	1.02	-0.58
1990	1.39	-0.13	1.00	-1.24
1991	1.06	-0.13	0.77	-1.14
1992	0.90	-0.41	0.68	-2.00
1993	0.97	-0.92	0.83	-2.72
1994	0.70	-1.03	0.63	-3.31
1995	0.71	-0.94	0.64	-3.00
1996	1.03	-1.23	0.88	-4.99
1997	0.73	-0.69	0.57	-4.74
1998	0.56	-0.41	0.43	-5.00
1999	0.66	-0.66	0.53	-4.60
2000	0.94	-0.86	0.77	-4.50
2001	0.96	-0.70	0.75	-3.45
2002	1.12	-0.60	0.84	-3.63

Table D1.24. Predation mortality (M2) values for age-0 and age-1 menhaden for the base run MSVPA-X configuration and for four scenarios in which the median size of prey selected for each predator was shifted by $\pm 10\%$ and $\pm 20\%$.

	Age-0					Age-1				
Year	Base Run	10% Decrease in Median Prey Size	10% Increase in Median Prey Size	20% Median Decrease in Median Prey Size	20% Median Increase in Median Prey Size	Base Run	10% Decrease in Median Prey Size	10% Increase in Median Prey Size	20% Median Decrease in Median Prey Size	20% Median Increase in Median Prey Size
1982	0.672	0.644	0.735	0.731	0.764	0.328	0.322	0.406	0.33	0.451
1983	0.607	0.578	0.664	0.662	0.691	0.276	0.279	0.35	0.28	0.392
1984	0.508	0.486	0.564	0.554	0.598	0.252	0.254	0.314	0.246	0.347
1985	0.542	0.498	0.632	0.618	0.705	0.241	0.253	0.307	0.233	0.34
1986	0.62	0.55	0.723	0.706	0.806	0.235	0.234	0.292	0.227	0.326
1987	0.637	0.541	0.742	0.725	0.819	0.193	0.181	0.245	0.188	0.285
1988	0.538	0.487	0.584	0.567	0.603	0.18	0.165	0.231	0.178	0.27
1989	0.396	0.369	0.423	0.397	0.433	0.167	0.158	0.216	0.155	0.244
1990	0.377	0.346	0.411	0.378	0.434	0.166	0.158	0.214	0.148	0.239
1991	0.404	0.369	0.432	0.401	0.453	0.162	0.153	0.208	0.143	0.232
1992	0.394	0.355	0.419	0.404	0.447	0.13	0.122	0.17	0.111	0.188
1993	0.534	0.47	0.564	0.55	0.601	0.148	0.141	0.197	0.124	0.218
1994	0.678	0.591	0.721	0.714	0.775	0.158	0.147	0.219	0.135	0.245
1995	0.854	0.783	0.839	0.843	0.837	0.188	0.172	0.262	0.172	0.304
1996	0.765	0.73	0.754	0.743	0.756	0.185	0.163	0.257	0.178	0.302
1997	0.752	0.709	0.746	0.721	0.742	0.191	0.161	0.267	0.189	0.314
1998	0.794	0.744	0.79	0.752	0.783	0.217	0.188	0.311	0.207	0.36
1999	0.745	0.692	0.743	0.71	0.741	0.214	0.19	0.307	0.195	0.354
2000	0.697	0.649	0.698	0.682	0.707	0.206	0.185	0.288	0.183	0.326
2001	0.835	0.754	0.87	0.856	0.907	0.228	0.205	0.316	0.204	0.356
2002	1.05	0.939	1.096	1.101	1.135	0.261	0.233	0.346	0.239	0.39

Table D1.25. Average recruited fishing mortality estimates for age-2+ menhaden from the base run configuration of the MSVPA-X and four scenarios in which the median size of prey selected for each predator was shifted by $\pm 10\%$ and $\pm 20\%$.

	Average Recruited F for Age 2+ Menhaden				
Year	BASE	(-)10% Median	(+)10% Median	(-)20% Median	(+)20% Median
1982	1.594	1.634	1.597	1.619	1.582
1983	1.442	1.47	1.441	1.461	1.429
1984	1.486	1.519	1.49	1.508	1.479
1985	1.534	1.568	1.538	1.559	1.524
1986	1.18	1.209	1.184	1.201	1.173
1987	1.053	1.073	1.055	1.068	1.046
1988	1.268	1.29	1.268	1.284	1.256
1989	1.219	1.238	1.213	1.234	1.198
1990	1.156	1.17	1.147	1.168	1.133
1991	1.363	1.379	1.353	1.377	1.335
1992	1.014	1.024	1.004	1.023	0.988
1993	1.036	1.046	1.021	1.046	1.004
1994	0.969	0.978	0.955	0.978	0.937
1995	1.237	1.249	1.221	1.248	1.187
1996	0.75	0.758	0.739	0.758	0.717
1997	0.915	0.923	0.905	0.922	0.878
1998	1.339	1.351	1.323	1.348	1.288
1999	1.182	1.193	1.166	1.191	1.135
2000	0.883	0.893	0.874	0.891	0.85
2001	1.243	1.257	1.233	1.254	1.202
2002	1.175	1.186	1.164	1.184	1.134

Table D1.26. Predation mortality (M2) estimates for age-0 through age-6 menhaden for the base run configuration for the MSVPA-X for two scenarios in which the range of prey size selectivity for each predator was increased or decrease by $\pm 10\%$.

M2	Age-0			Age-1			Age-2			Age-3			Age-4		
Year	Base	-10%	+10%	Base	-10%	+10%	Base	-10%	+10%	Base	-10%	+10%	Base	-10%	+10%
1982	0.672	0.994	0.628	0.328	0.204	0.319	0.207	0.018	0.202	0.137	0.002	0.137	0.091	0	0.095
1983	0.607	0.895	0.567	0.276	0.175	0.271	0.171	0.016	0.168	0.113	0.002	0.114	0.075	0	0.079
1984	0.508	0.734	0.481	0.252	0.148	0.246	0.168	0.015	0.164	0.113	0.002	0.114	0.075	0	0.079
1985	0.542	0.763	0.518	0.241	0.143	0.236	0.164	0.015	0.16	0.11	0.002	0.111	0.073	0	0.077
1986	0.62	0.803	0.589	0.235	0.113	0.232	0.158	0.012	0.154	0.108	0.001	0.108	0.073	0	0.077
1987	0.637	0.748	0.598	0.193	0.069	0.195	0.119	0.007	0.117	0.079	0.001	0.08	0.054	0	0.057
1988	0.538	0.68	0.499	0.18	0.068	0.183	0.099	0.006	0.1	0.064	0.001	0.066	0.043	0	0.047
1989	0.396	0.543	0.362	0.167	0.073	0.166	0.093	0.007	0.095	0.059	0.001	0.062	0.04	0	0.043
1990	0.377	0.488	0.351	0.166	0.082	0.164	0.093	0.01	0.096	0.058	0.002	0.062	0.038	0	0.043
1991	0.404	0.527	0.373	0.162	0.076	0.161	0.087	0.01	0.091	0.054	0.002	0.059	0.037	0.001	0.042
1992	0.394	0.517	0.369	0.13	0.067	0.13	0.062	0.008	0.066	0.036	0.001	0.041	0.025	0	0.029
1993	0.534	0.681	0.503	0.148	0.081	0.149	0.068	0.011	0.074	0.039	0.002	0.045	0.027	0.001	0.032
1994	0.678	0.852	0.631	0.158	0.091	0.162	0.068	0.013	0.075	0.038	0.002	0.044	0.025	0.001	0.031
1995	0.854	1.098	0.799	0.188	0.104	0.198	0.072	0.014	0.082	0.039	0.002	0.047	0.026	0.001	0.033
1996	0.765	0.99	0.711	0.185	0.094	0.2	0.063	0.012	0.073	0.032	0.002	0.039	0.02	0	0.026
1997	0.752	1.016	0.684	0.191	0.087	0.205	0.06	0.009	0.071	0.028	0.001	0.035	0.017	0	0.022
1998	0.794	1.07	0.715	0.217	0.103	0.229	0.07	0.012	0.083	0.033	0.002	0.041	0.02	0	0.026
1999	0.745	1.015	0.67	0.214	0.103	0.224	0.073	0.011	0.086	0.035	0.001	0.044	0.021	0	0.027
2000	0.697	0.924	0.636	0.206	0.098	0.214	0.077	0.01	0.089	0.038	0.001	0.047	0.023	0	0.03
2001	0.835	1.098	0.761	0.228	0.105	0.234	0.09	0.011	0.101	0.046	0.001	0.055	0.028	0	0.035
2002	1.05	1.334	0.961	0.261	0.115	0.267	0.109	0.013	0.119	0.057	0.002	0.067	0.035	0	0.044

Table D1.26 (Cont'd). Predation mortality (M2) estimates for age-0 through age-6 menhaden for the base run configuration for the MSVPA-X for two scenarios in which the range of prey size selectivity for each predator was increased or decrease by $\pm 10\%$.

M2	Age-5			Age-6		
Year	Base	-10%	+10%	Base	-10%	+10%
1982	0.062	0	0.068	0.043	0	0.05
1983	0.051	0	0.057	0.035	0	0.041
1984	0.051	0	0.057	0.035	0	0.041
1985	0.05	0	0.055	0.034	0	0.04
1986	0.051	0	0.057	0.035	0	0.041
1987	0.039	0	0.043	0.029	0	0.033
1988	0.031	0	0.035	0.023	0	0.027
1989	0.028	0	0.032	0.021	0	0.025
1990	0.027	0	0.031	0.02	0	0.024
1991	0.028	0	0.033	0.02	0	0.025
1992	0.02	0	0.024	0.016	0	0.02
1993	0.021	0	0.026	0.017	0	0.022
1994	0.02	0	0.025	0.016	0	0.021
1995	0.02	0	0.026	0.016	0	0.021
1996	0.015	0	0.019	0.012	0	0.016
1997	0.012	0	0.016	0.009	0	0.012
1998	0.014	0	0.019	0.01	0	0.014
1999	0.015	0	0.02	0.011	0	0.015
2000	0.016	0	0.022	0.012	0	0.017
2001	0.02	0	0.026	0.015	0	0.02
2002	0.025	0	0.033	0.019	0	0.026

Table D1.27. Total biomass (000 MT) consumed by bluefish for the base run configuration for the MSVPA-X for two scenarios in which the range of prey size selectivity for each predator was increased or decrease by $\pm 10\%$.

Year	Base Run	Decreased Range	Increased Range
1982	558.72	724.41	560.67
1983	428.04	673.61	434.35
1984	487.23	671.36	491.3
1985	452.55	691.32	457.97
1986	469.84	603.41	469.9
1987	359.98	407.24	360.39
1988	315.98	367.03	315.59
1989	283.69	305.33	282.91
1990	263.72	295.18	264.08
1991	261.59	253.08	261.45
1992	197.03	187.96	197.13
1993	177.53	177.99	178.47
1994	154.36	162.96	154.6
1995	184.95	157.04	185.39
1996	182.73	141.69	182.92
1997	178.99	138.39	179.08
1998	186.09	148.96	185.78
1999	244.06	203.46	243.54
2000	272.14	227.37	272.01
2001	353.88	262.26	352.76
2002	409.46	359.72	409.18

APPENDIX D1 FIGURES

Figure D1.1. Plot of menhaden fishing mortality over time to investigate retrospective bias in terminal year F estimation in MSVPA-X.

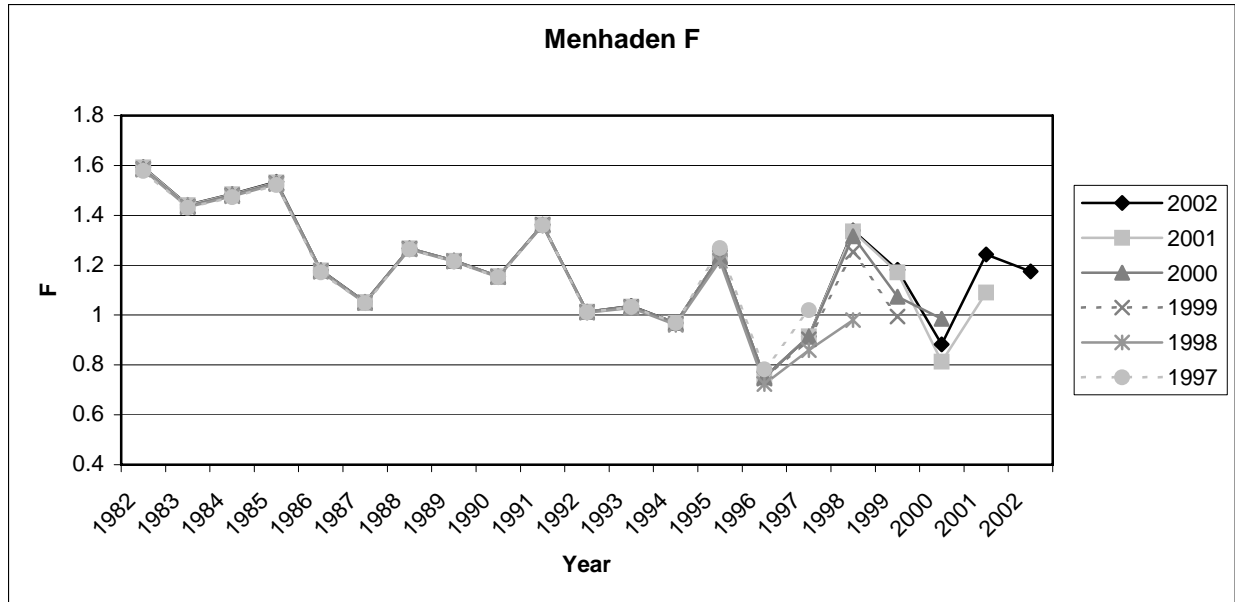


Figure D1.2. Plot of menhaden spawning stock biomass (SSB in 000 mt) over time to investigate retrospective bias in terminal year SSB estimation in MSVPA-X.

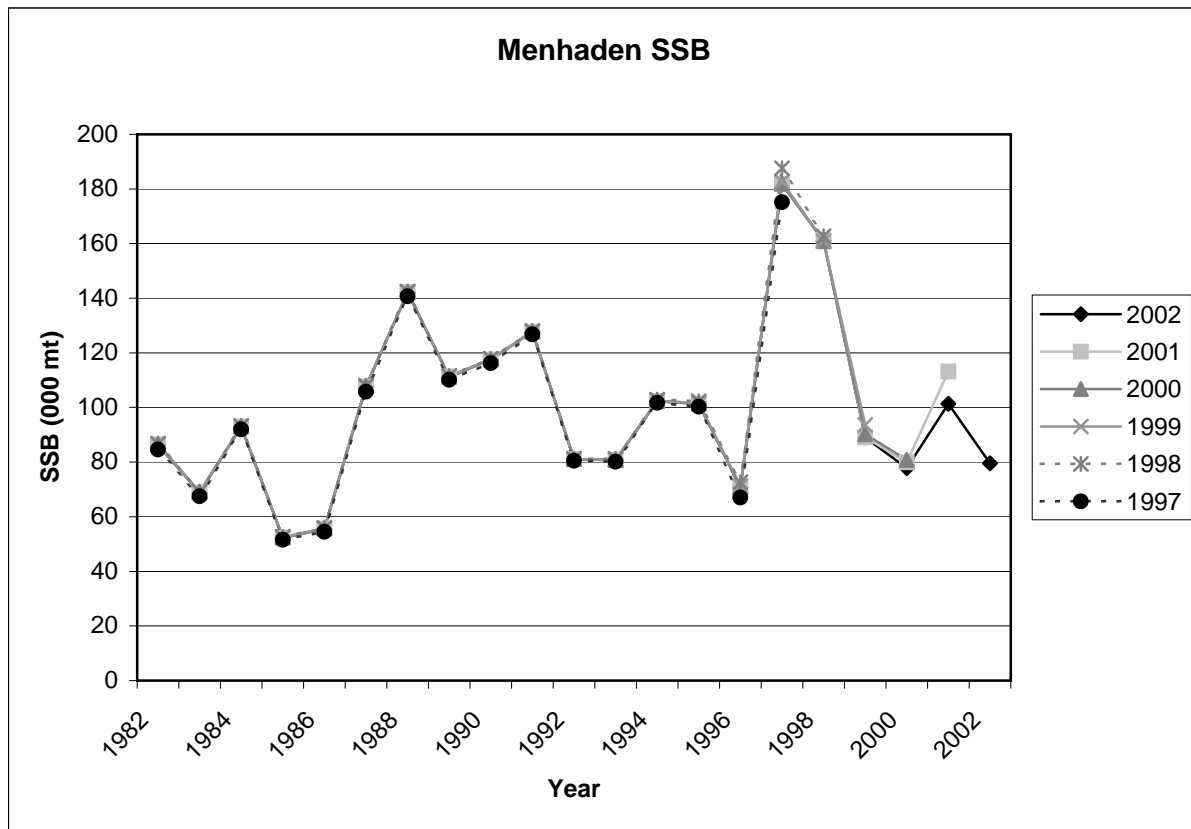


Figure D1.3. Plot of striped bass fishing mortality (F) over time to investigate retrospective bias in terminal year F estimation in MSVPA-X.

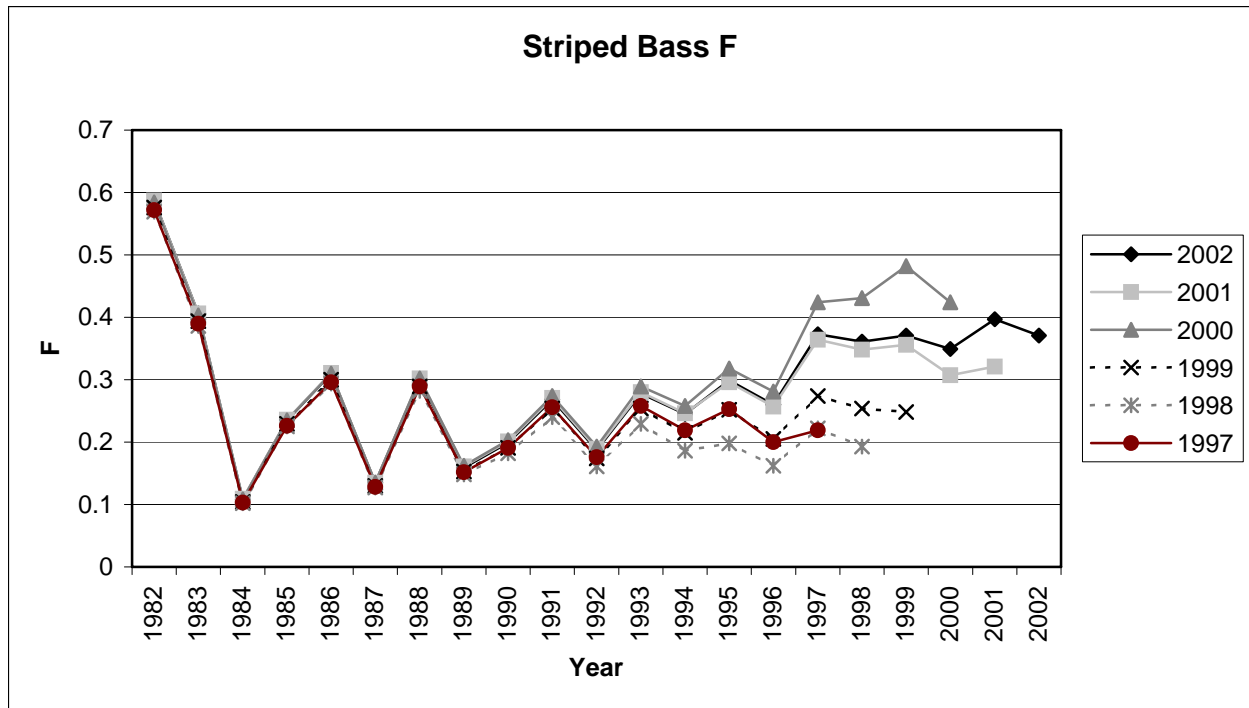


Figure D1.4. Plot of striped bass spawning stock biomass (SSB in 000 mt) over time to investigate retrospective bias in terminal year SSB estimation in MSVPA-X.

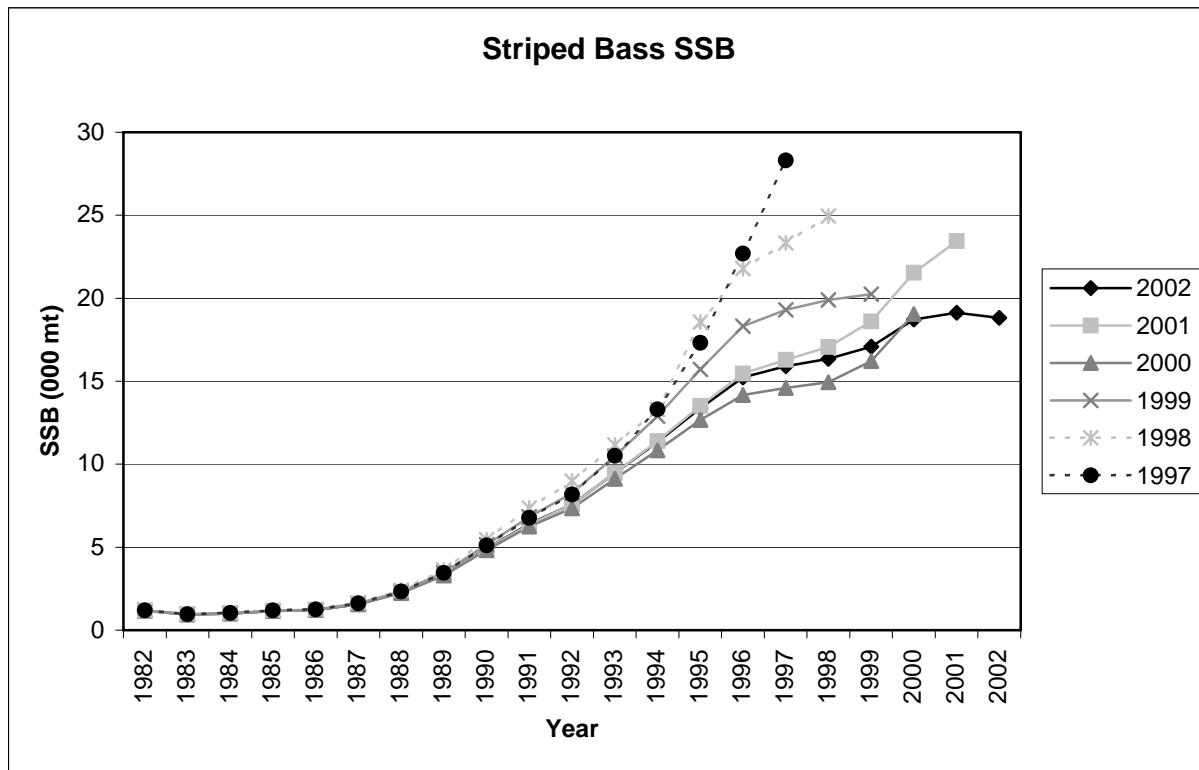


Figure D1.5. Plot of weakfish fishing mortality (F) over time to investigate retrospective bias in terminal year F estimation in MSVPA-X.

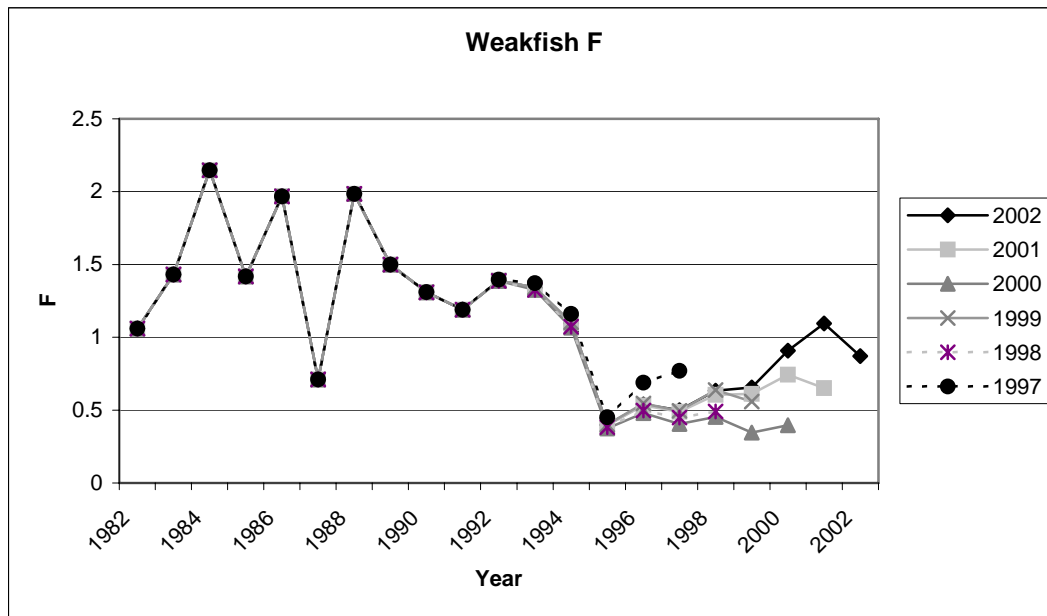


Figure 1.6. Plot of weakfish spawning stock biomass (SSB in 000 mt) over time to investigate retrospective bias in terminal year SSB estimation in MSVPA-X.

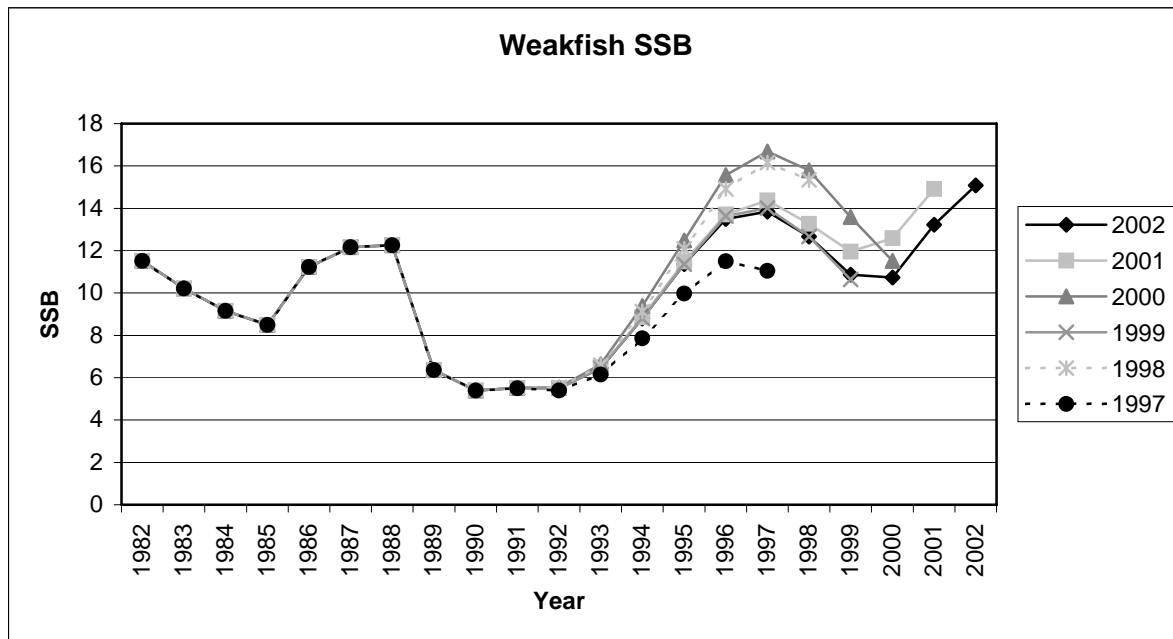


Figure D1.7. Terminal year predation mortality (M2) estimates for age-0 menhaden over time to investigate terminal year bias in M2 estimation in the MSVPA-X model.

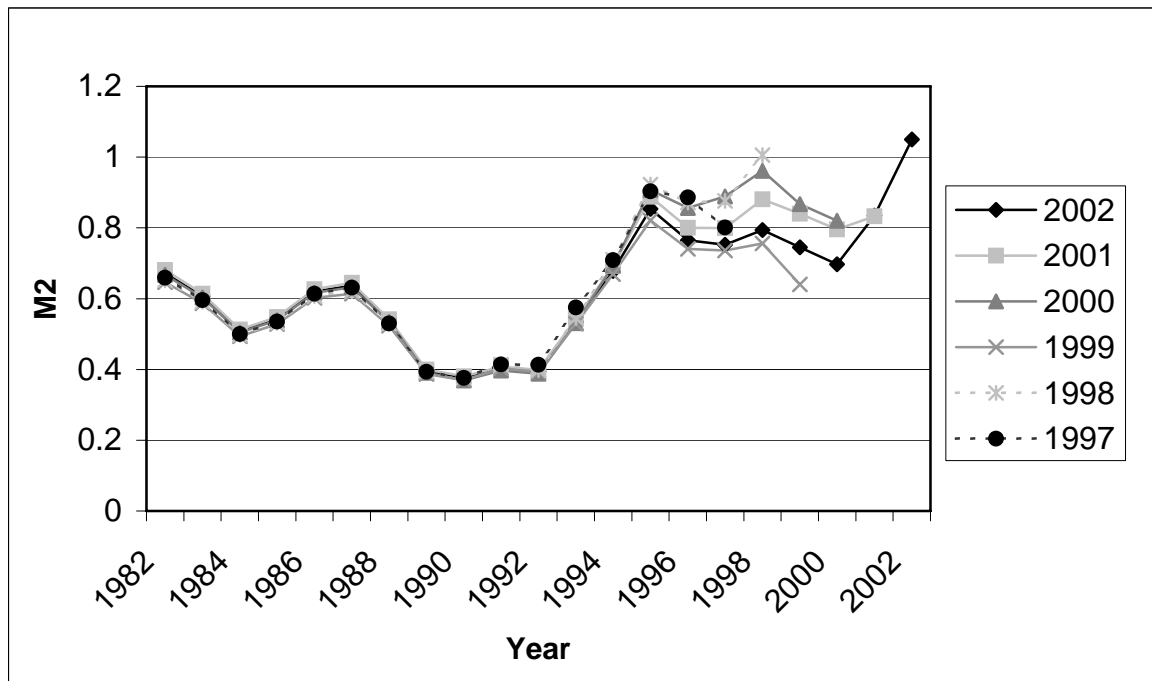


Figure D1.8. Predation mortality estimates for age-0 menhaden for the base run and 3 scenarios where one “other prey” group was removed. Runs were made with the removal of each of the following groups: bay anchovy, clupeids, and medium forage fish.

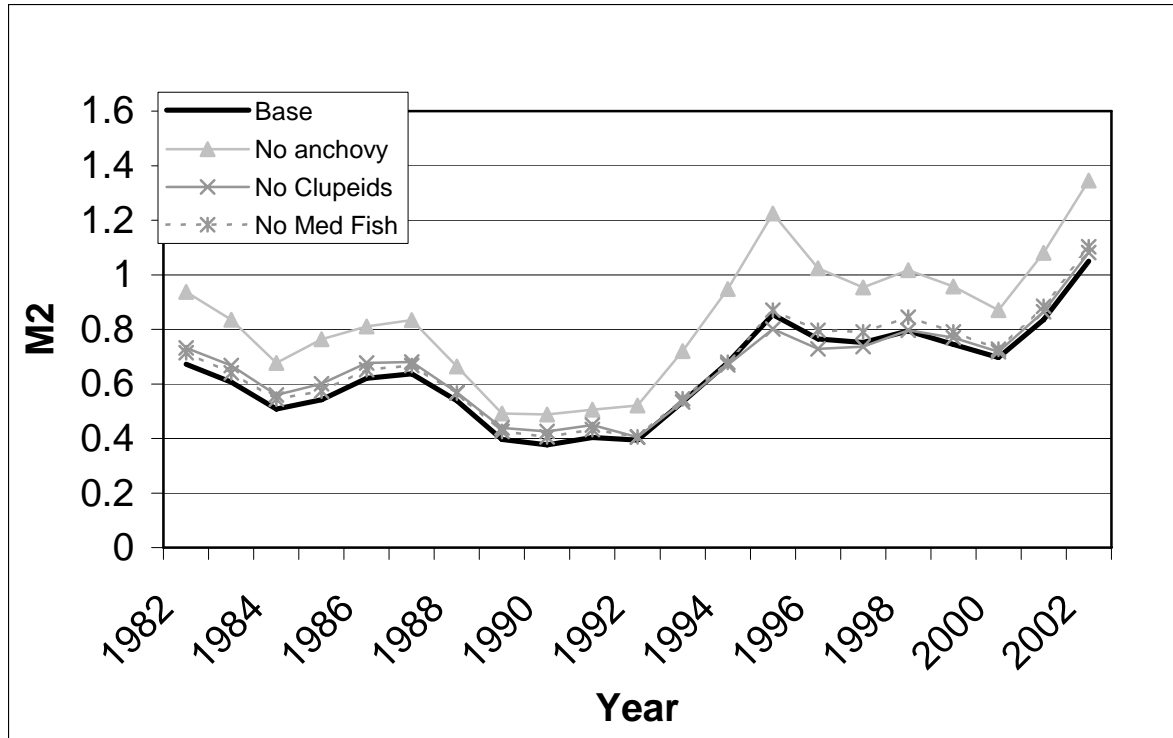


Figure D1.9. Spawning stock biomass (SSB in 000 mt) estimates for menhaden for the base run and 3 scenarios where one “other prey” group was removed. Runs were made with the removal of each of the following groups: bay anchovy, clupeids, and medium forage fish.

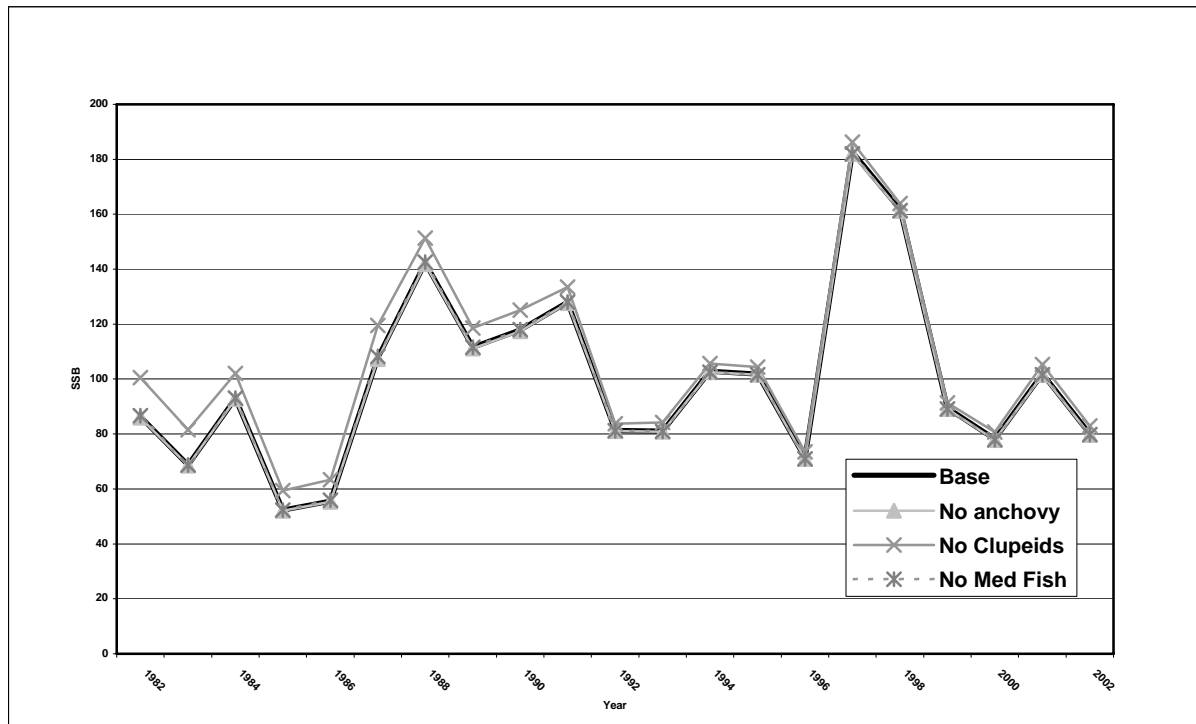


Figure D1.10. The average diet composition across years modeled (1982-2002) for striped bass by age in the base run MSVPA-X model.



Figure 1.11. The average diet composition across years modeled (1982-2002) for striped bass by age in the 'no anchovy run' in the MSVPA-X model.



Figure D1.12. The average diet composition across years modeled (1982-2002) for striped bass by age in the ‘no clupeids run’ in the MSVPA-X model.

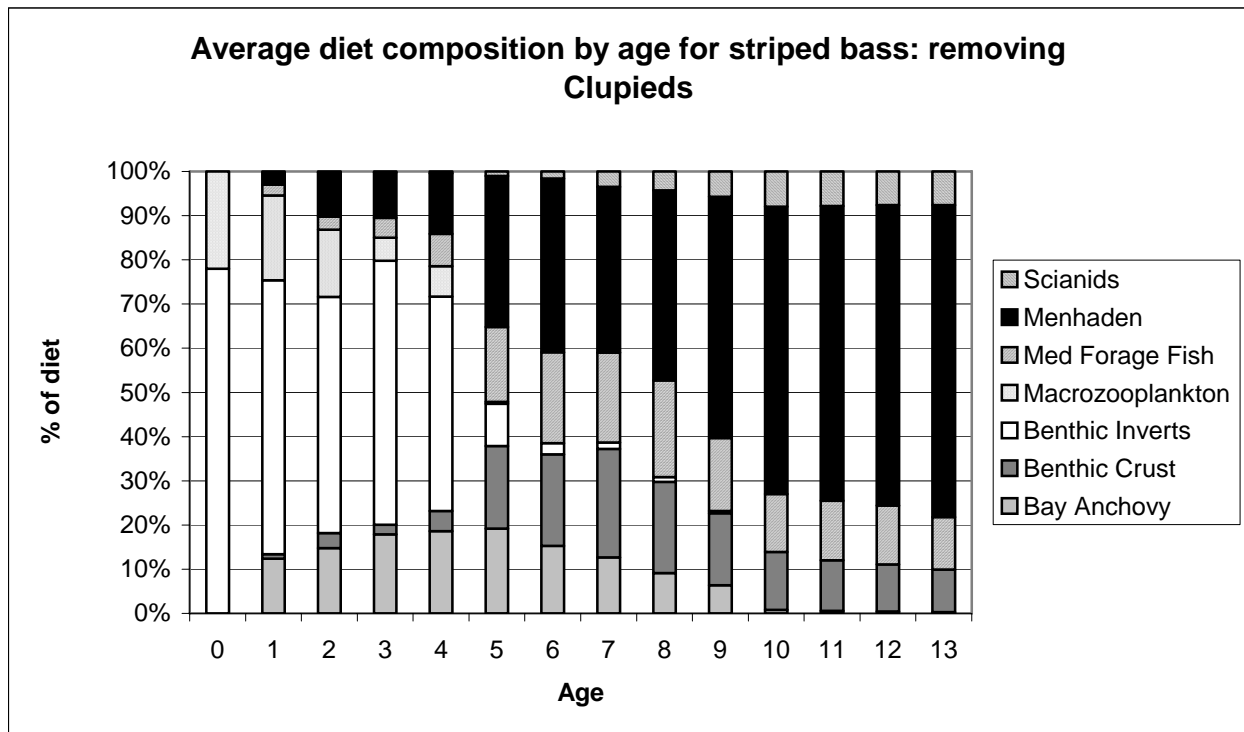


Figure D1.13. The average diet composition across years modeled (1982-2002) for striped bass by age in the ‘no medium forage fish run’ in the MSVPA-X model.

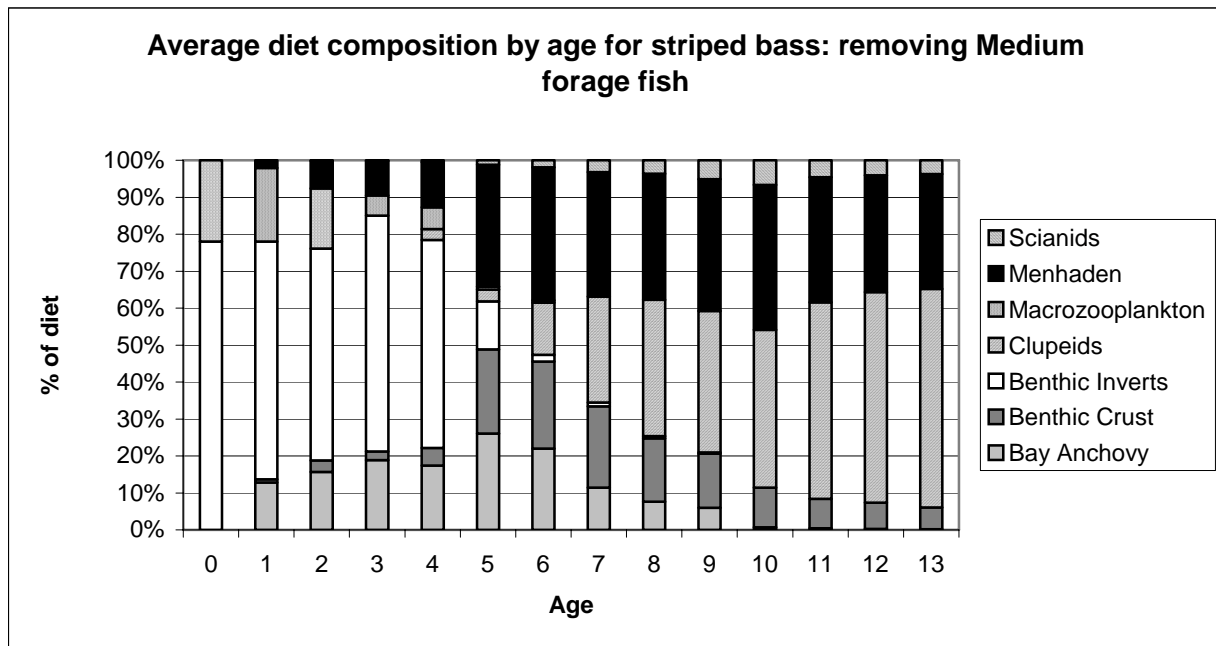


Figure D1.14. Predation mortality (M2) by predator and year for age-0 menhaden in the base run of the MSVPA-X model.

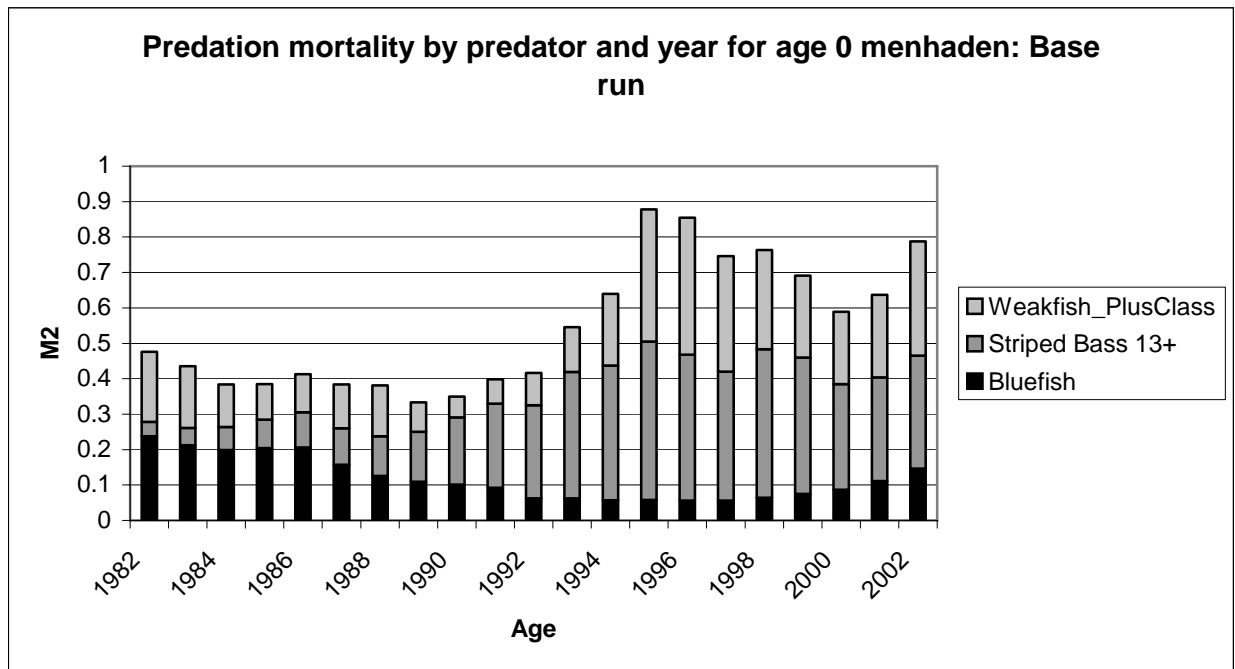


Figure D1.15. Predation mortality (M2) by predator and year for age-0 menhaden in the ‘no clupeid run’ of the MSVPA-X model.

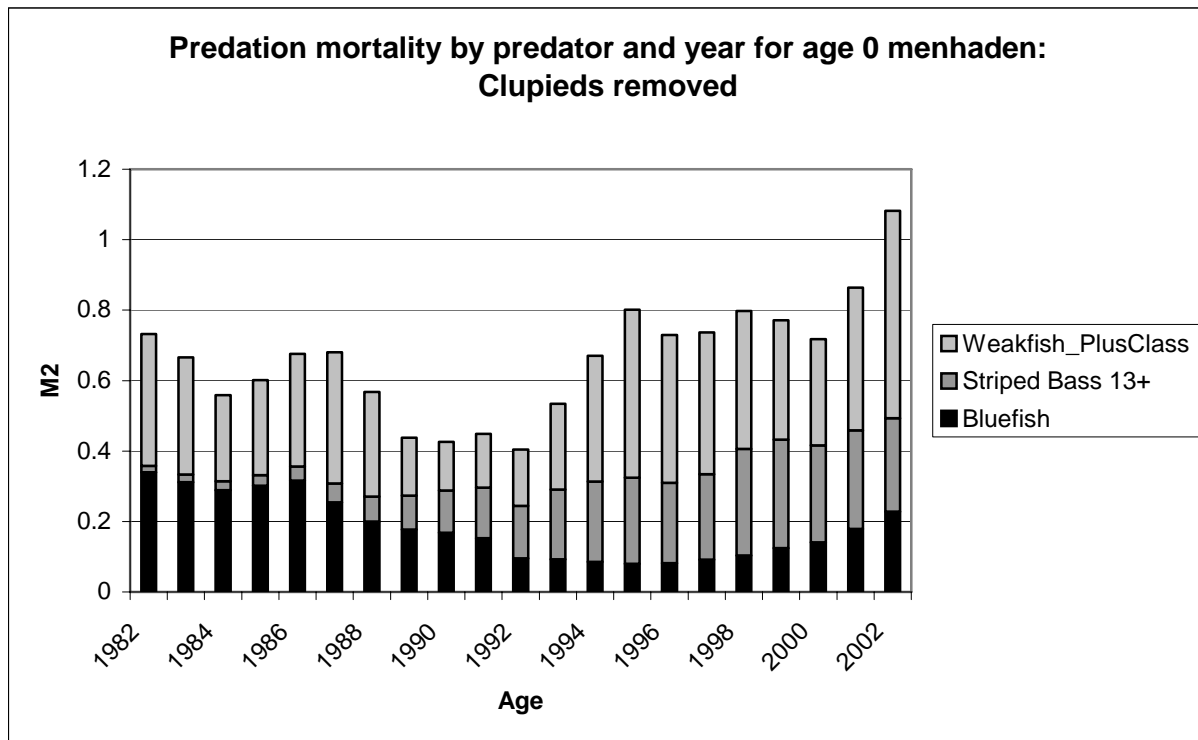


Figure D1.16. Predation mortality (M2) by predator and year for age-0 menhaden in the ‘no anchovy run’ of the MSVPA-X model.

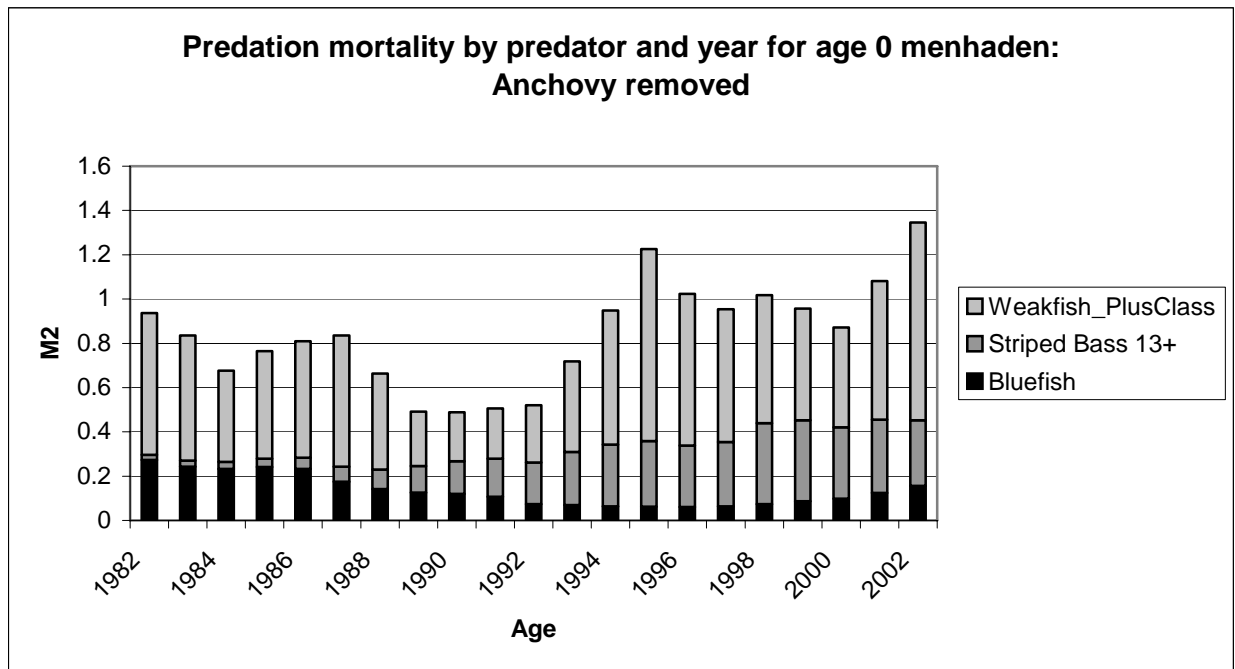


Figure D1.17. Predation mortality (M2) by predator and year for age-0 menhaden in the ‘no medium forage fish run’ of the MSVPA-X model.

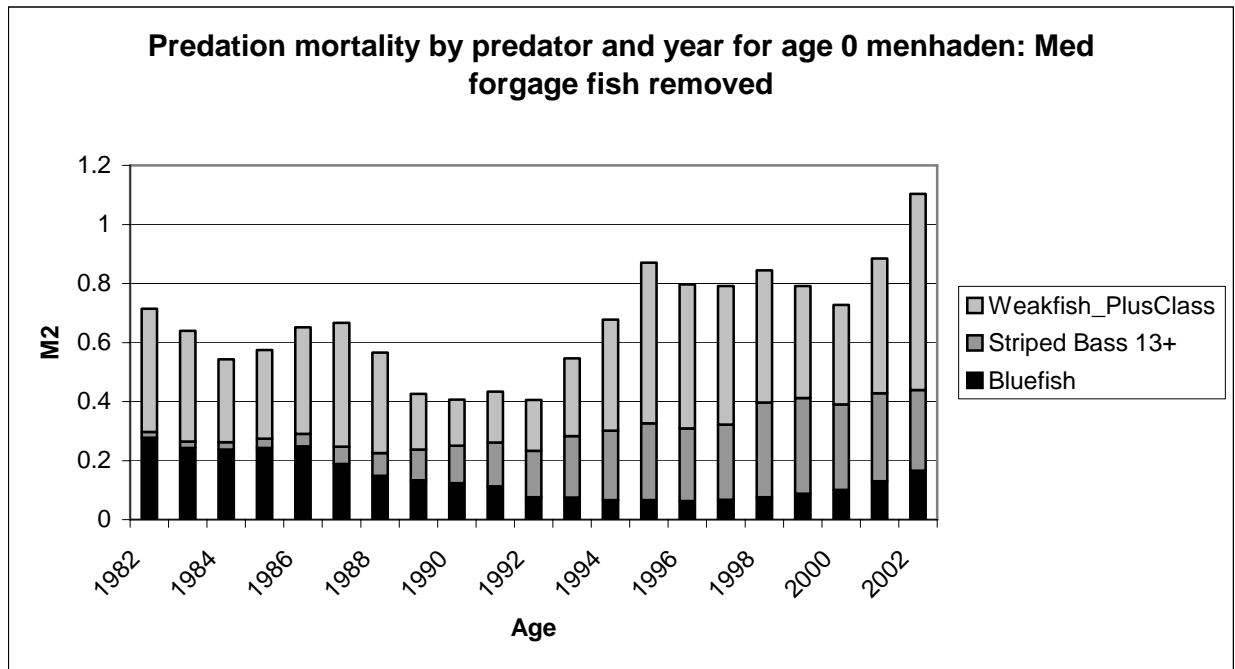


Figure D1.18. Total abundance of menhaden population at different values of M1.

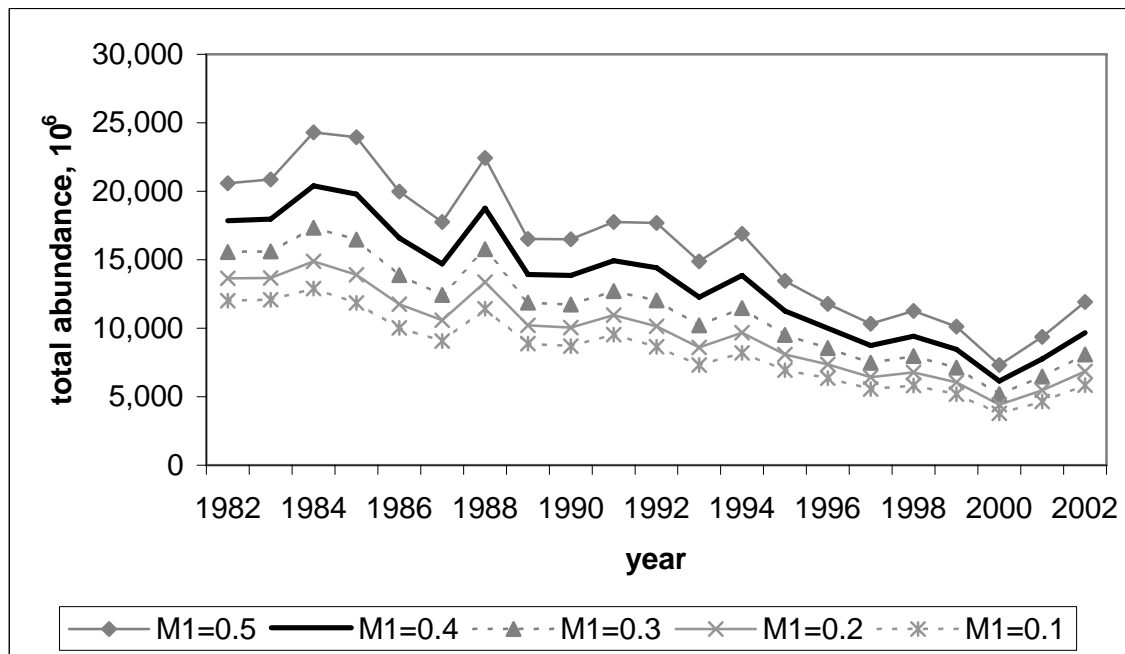


Figure D1.19. Relative changes in menhaden abundance in response to changes in M1.

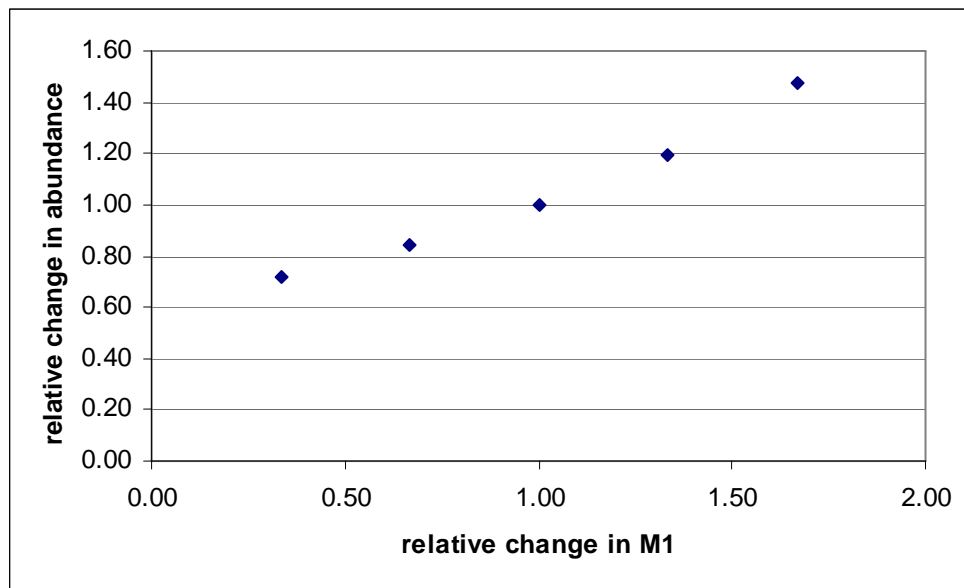


Figure D1.20. Total abundance of age-0 menhaden at different values of M1.

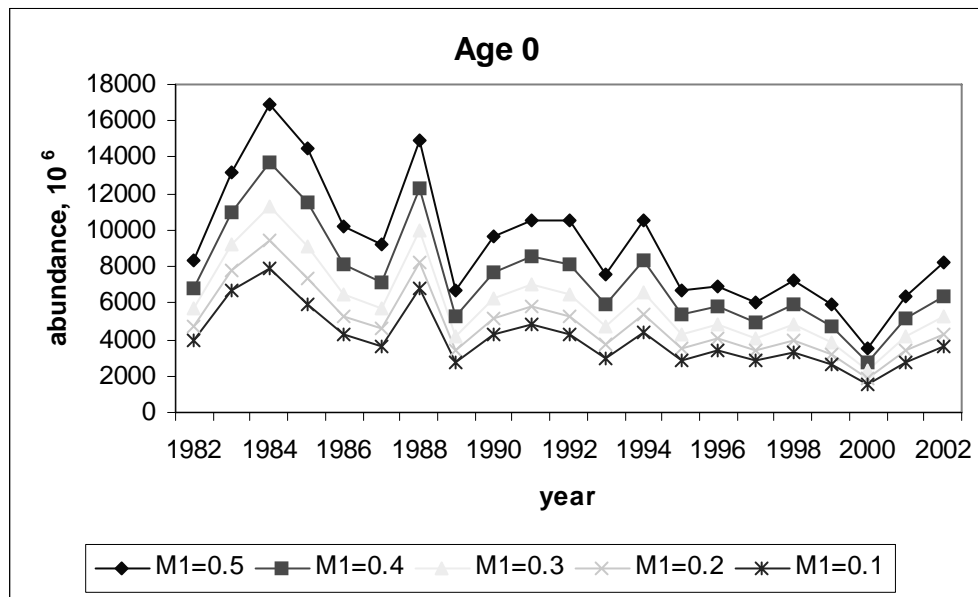


Figure D1.21. Total abundance of age-1 menhaden at different values of M1.

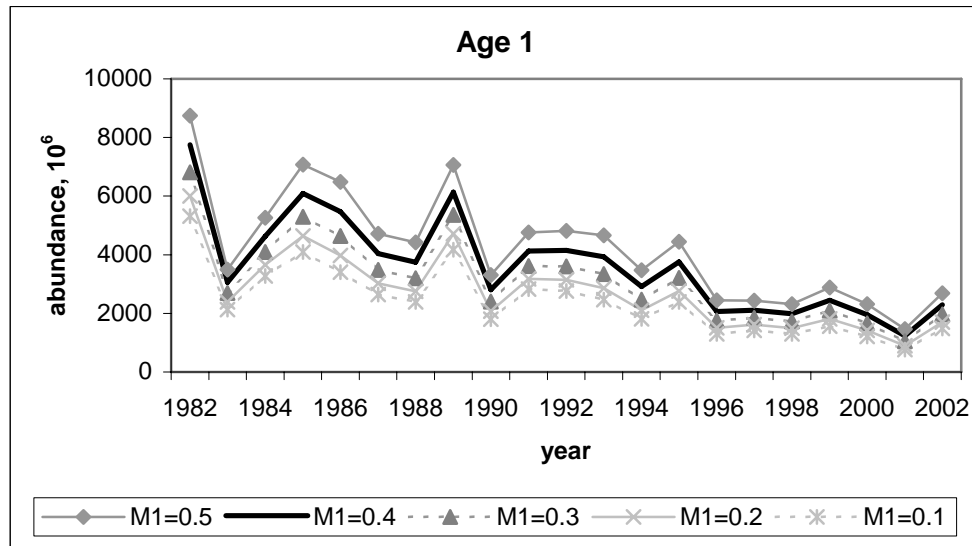


Figure D1.22. Total biomass of menhaden population at different values of M1.

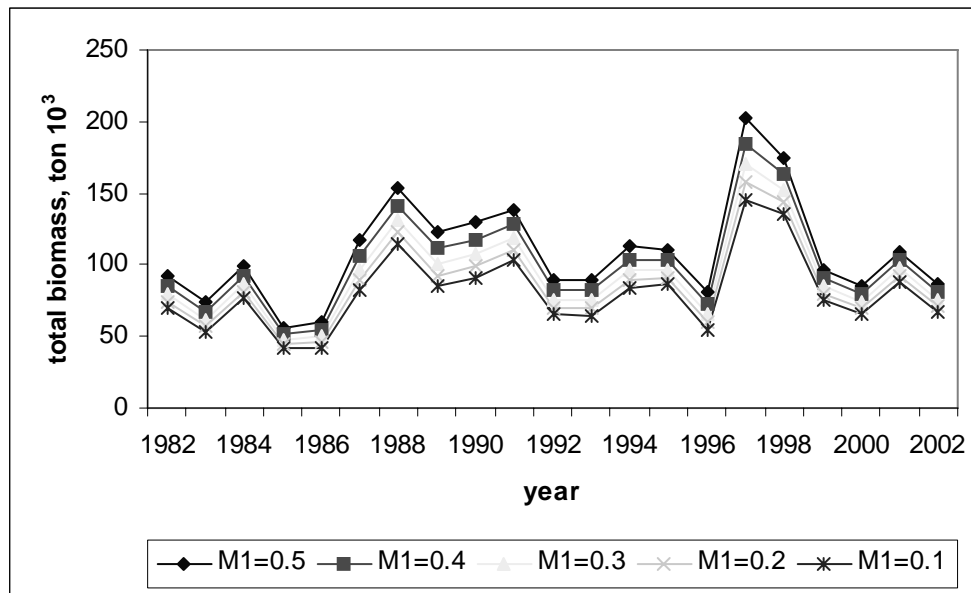


Figure D1.23. Spawning stock biomass of menhaden population at different values of M1.

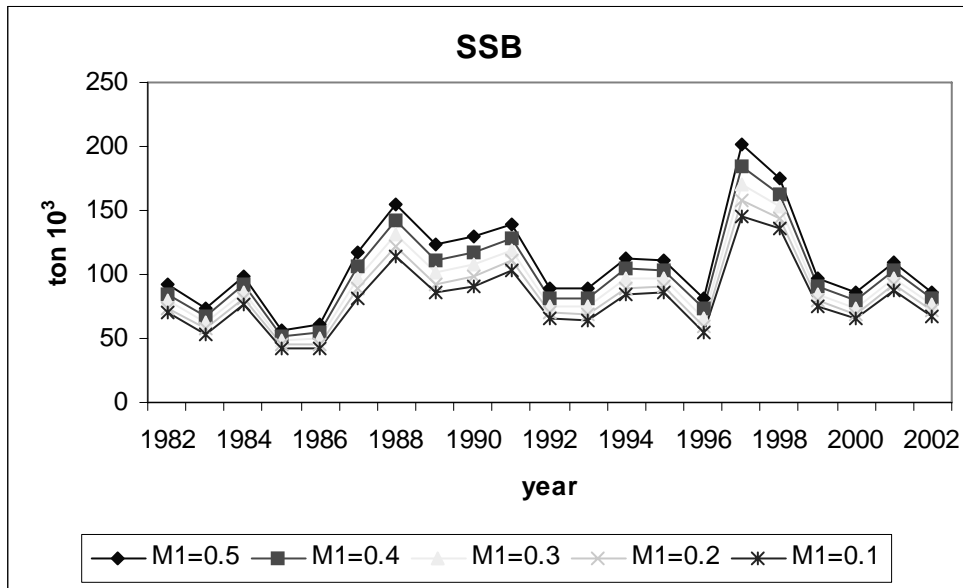


Figure D1.24. Average fishing mortality for fully recruited age groups and different M1 values.

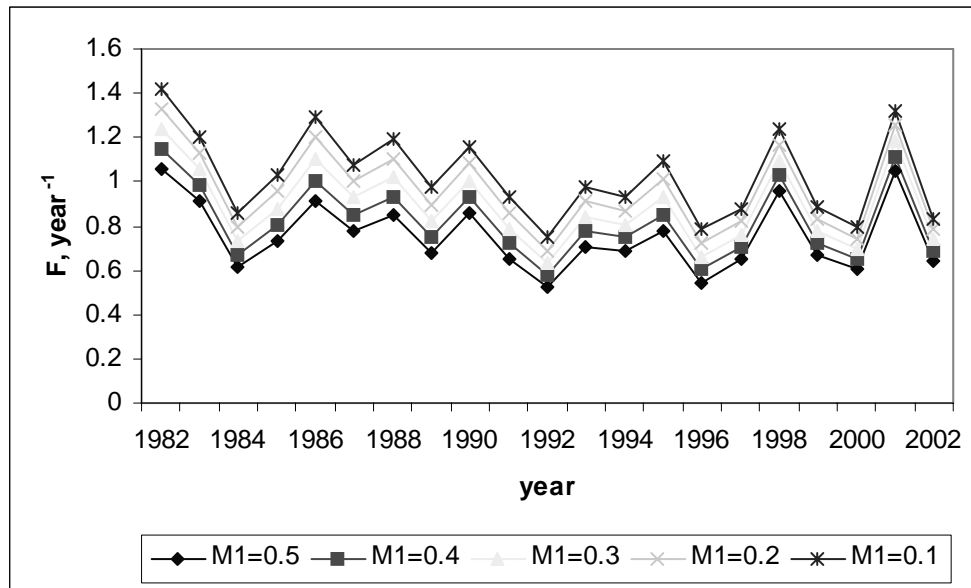


Figure D1.25. Predation mortality (M2) for fully age-0 menhaden and different M1 values.

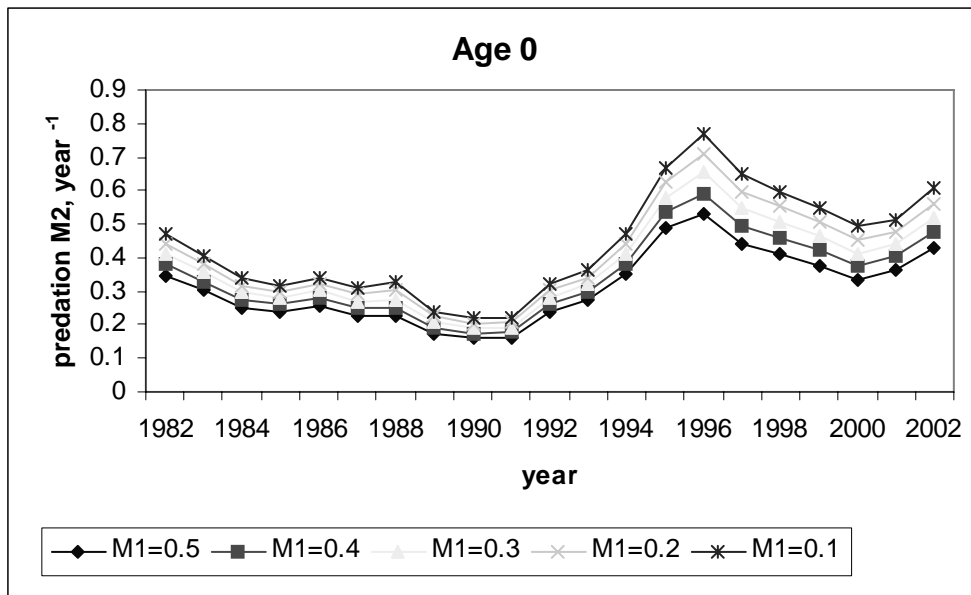


Figure D1.26. Predation mortality (M2) for fully age-1 menhaden and different M1 values.

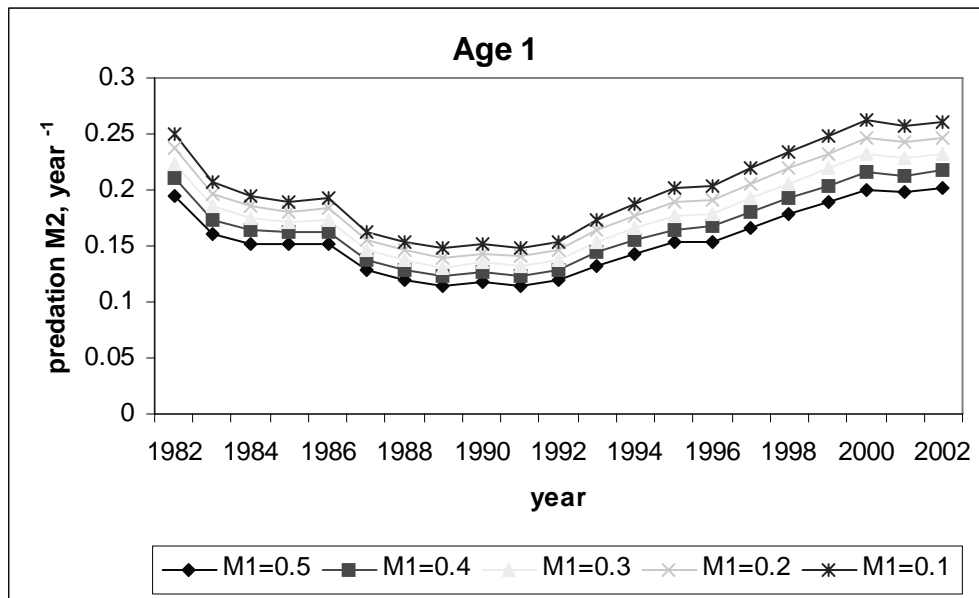


Figure D1.27. Impact of alternative values for the gastric evacuation rate parameter α on the abundance (millions of fish) of age-0 abundance of menhaden in the MSVPA-X model.

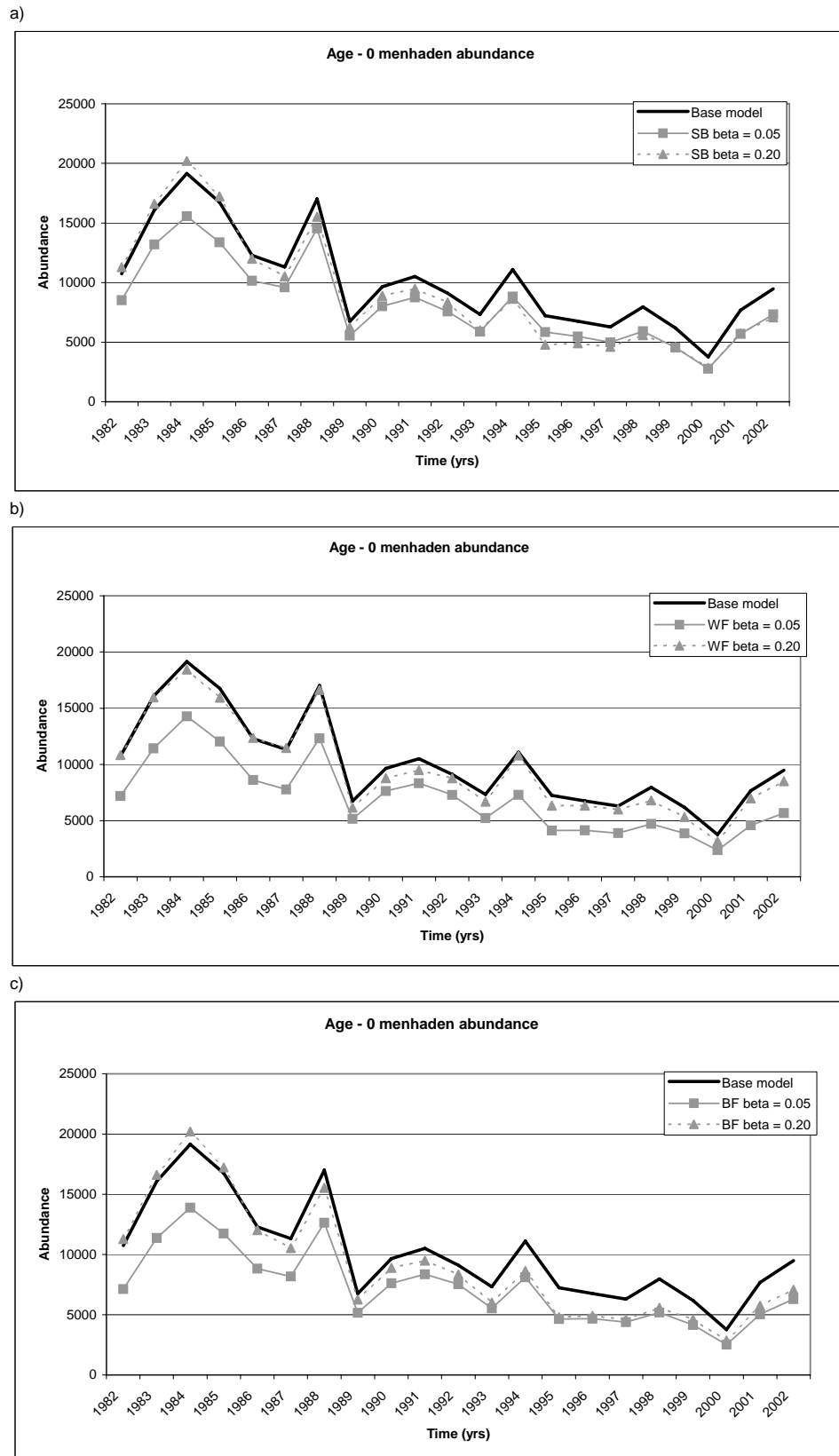


Figure D1.28. Impact of alternative values for the gastric evacuation rate parameter β on the abundance (millions of fish) of age-0 abundance of menhaden in the MSVPA-X model.

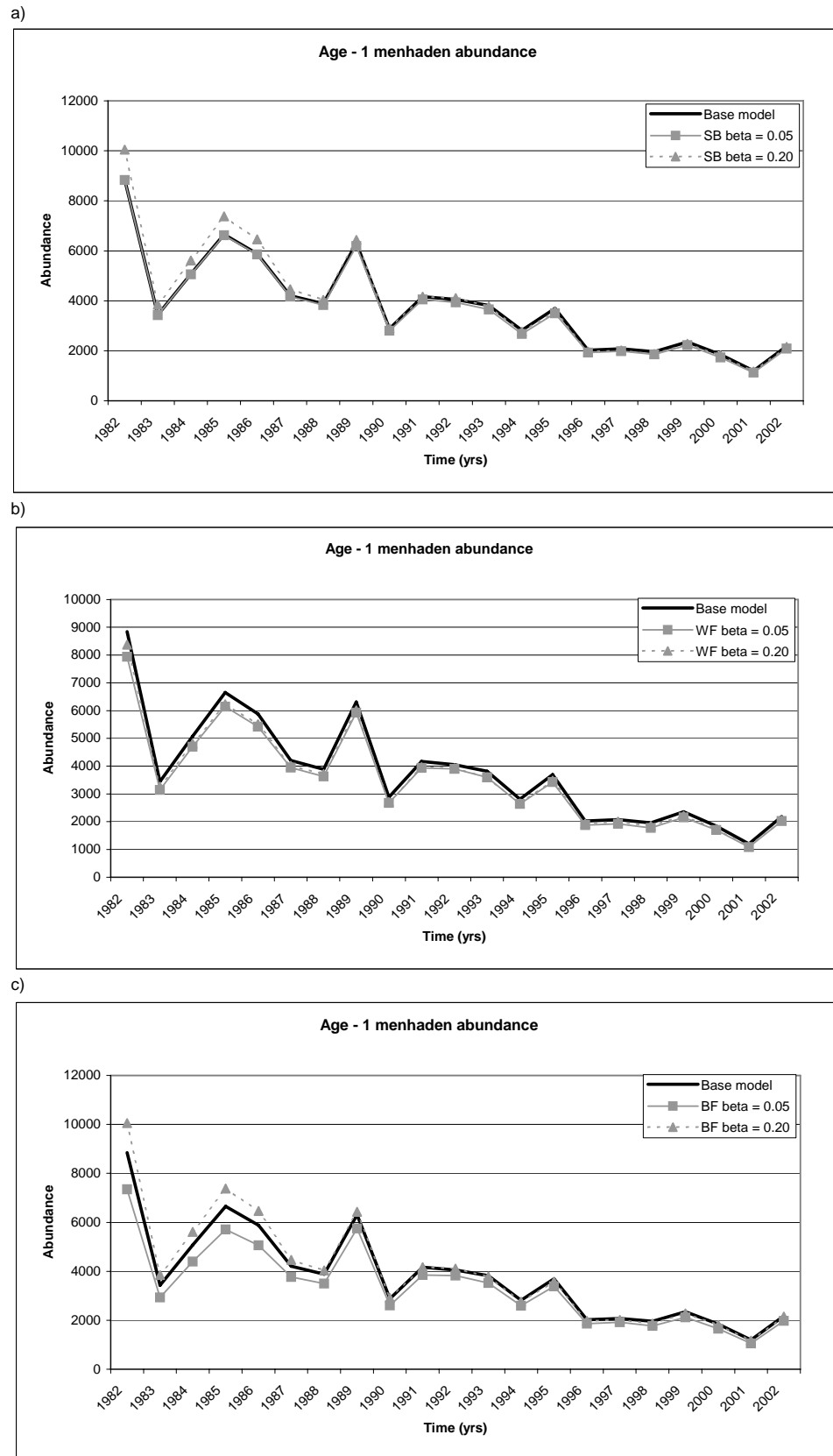


Figure D1.29. The affect of changing the gastric evacuation parameter α for weakfish on the predation mortality (M2) on a) age-0 and b) age-1 menhaden.

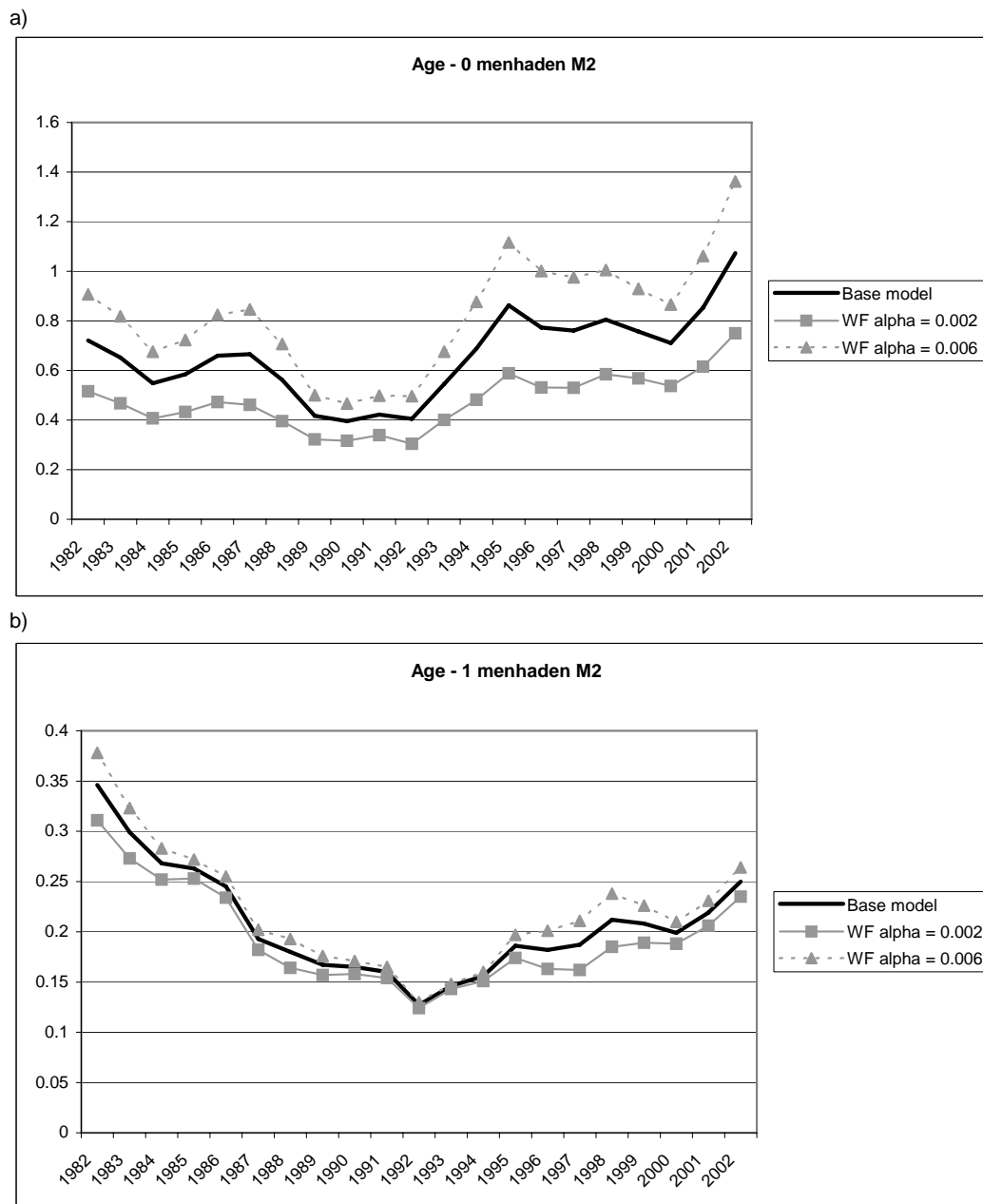
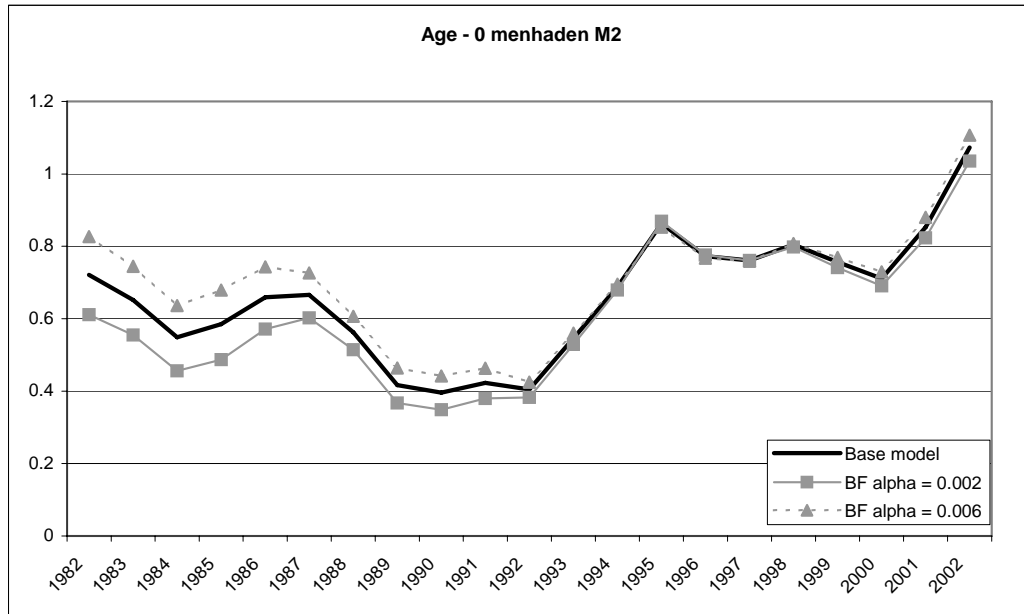


Figure D1.30. The affect of changing the gastric evacuation parameter α for bluefish on the predation mortality (M2) on a) age-0 and b) age-1 menhaden.

a)



b)

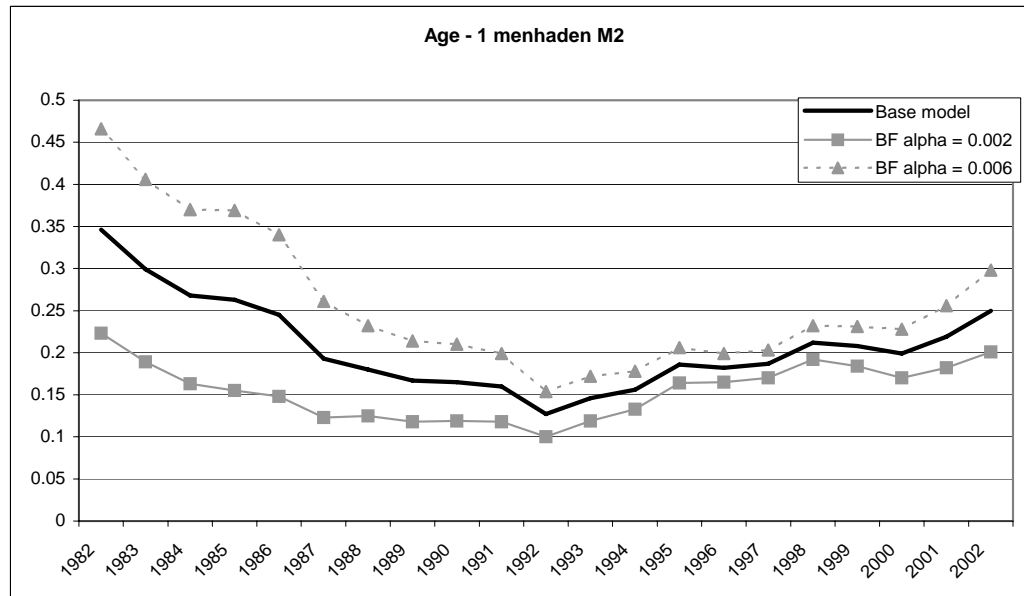


Figure D1.31. The affect of changing the gastric evacuation parameter α for striped bass on the predation mortality (M2) on a) age-0 and b) age-1 menhaden.

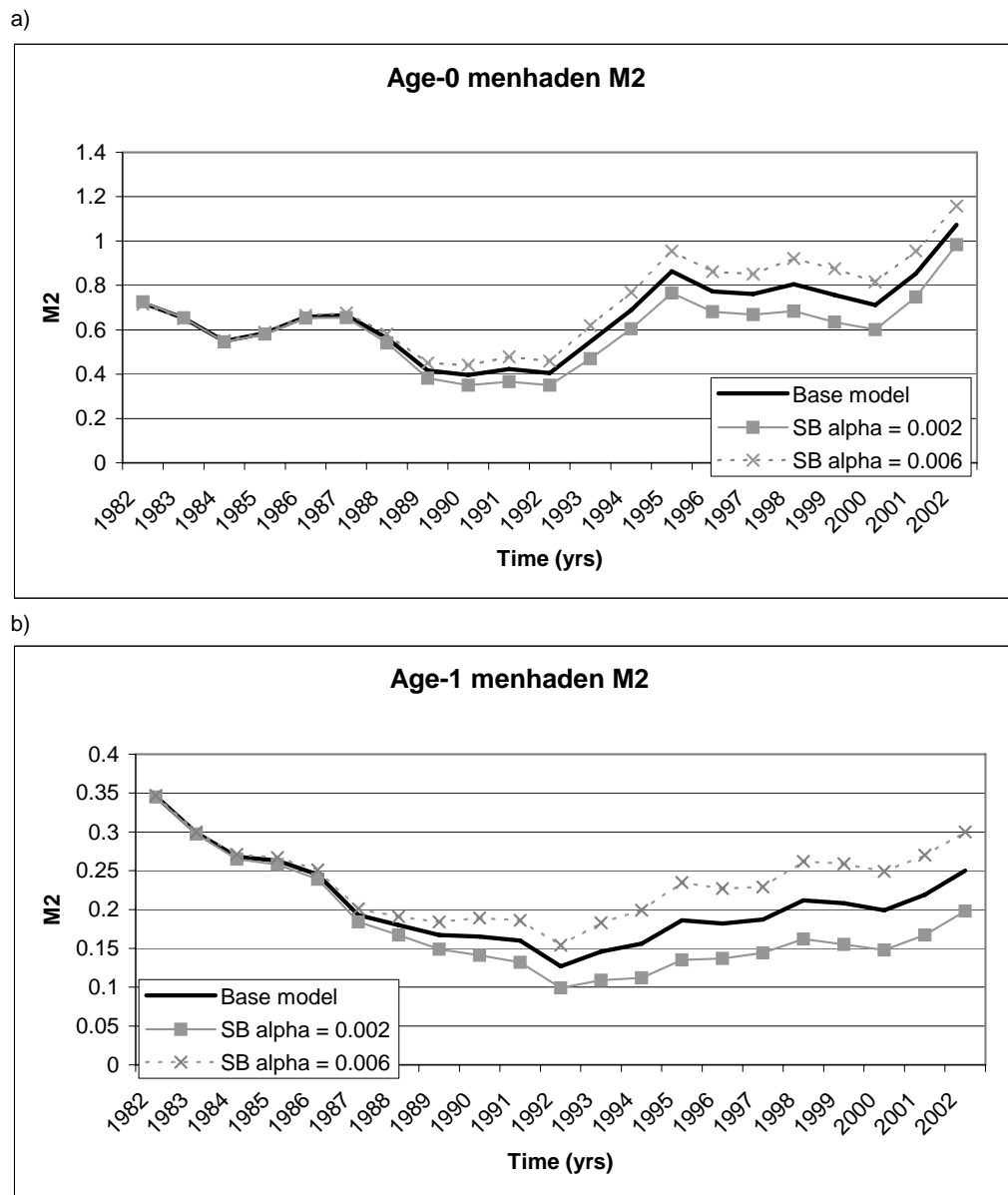


Figure D1.32. The affect of changing the gastric evacuation parameter β for weakfish on the predation mortality (M2) on a) age-0 and b) age-1 menhaden

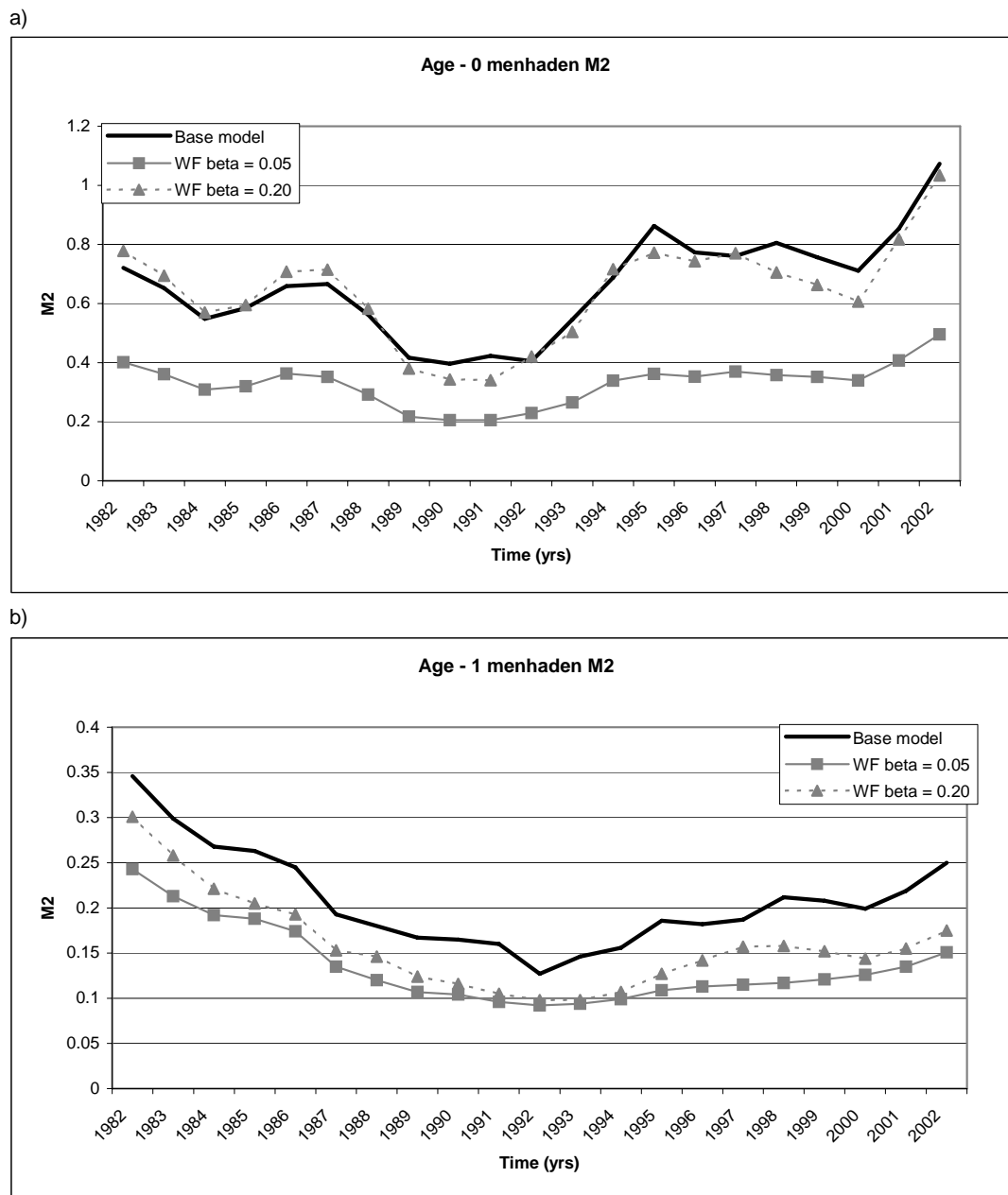


Figure D1.33. The affect of changing the gastric evacuation parameter β for bluefish on the predation mortality (M2) on a) age-0 and b) age-1 menhaden

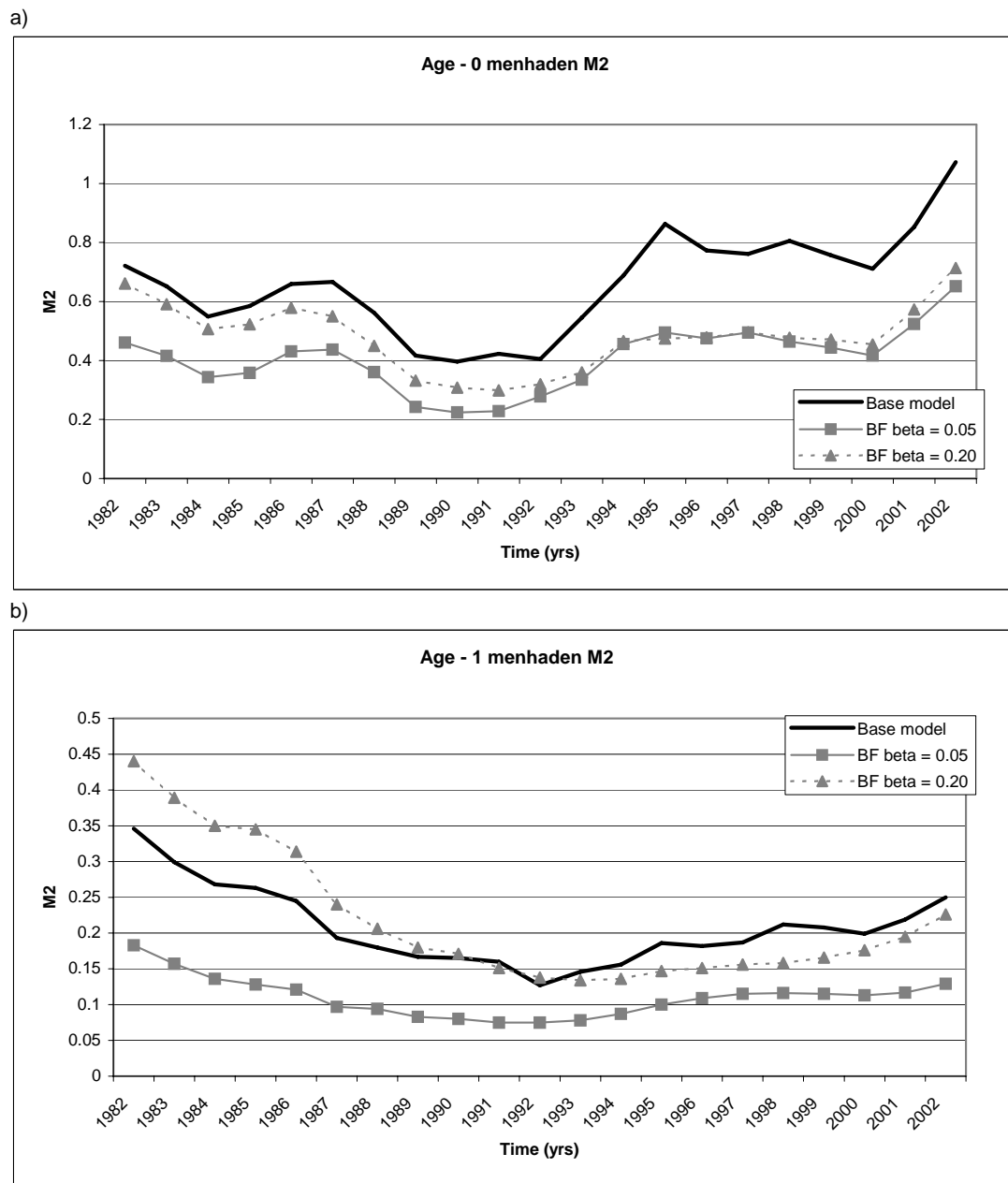


Figure D1.34. The affect of changing the gastric evacuation parameter β for striped bass on the predation mortality (M2) on a) age-0 and b) age-1 menhaden.

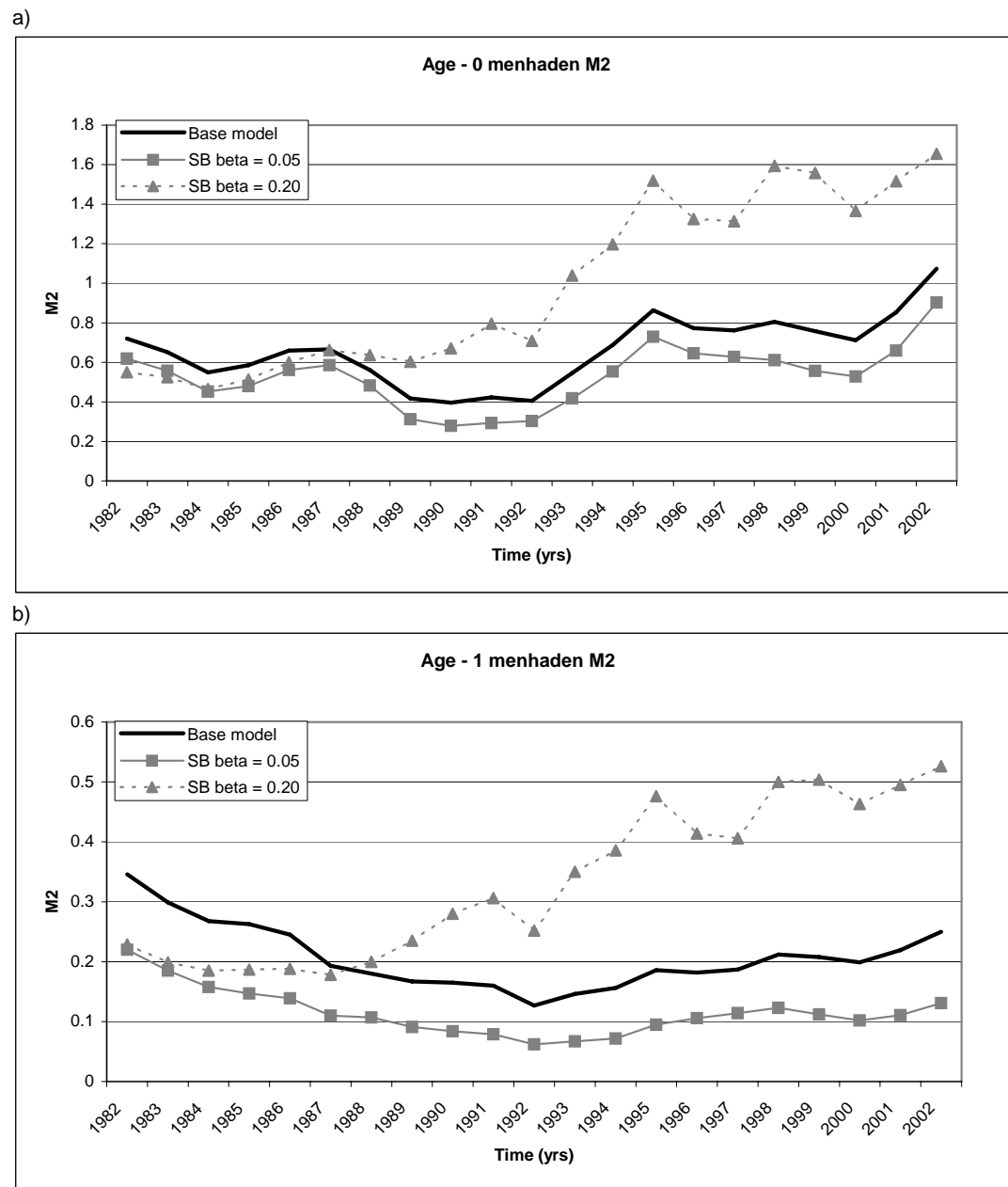


Figure D1.35. The affect of changing the gastric evacuation parameter α for striped bass on the consumption (000 mt) of a) striped bass, b) weakfish, and c) bluefish.

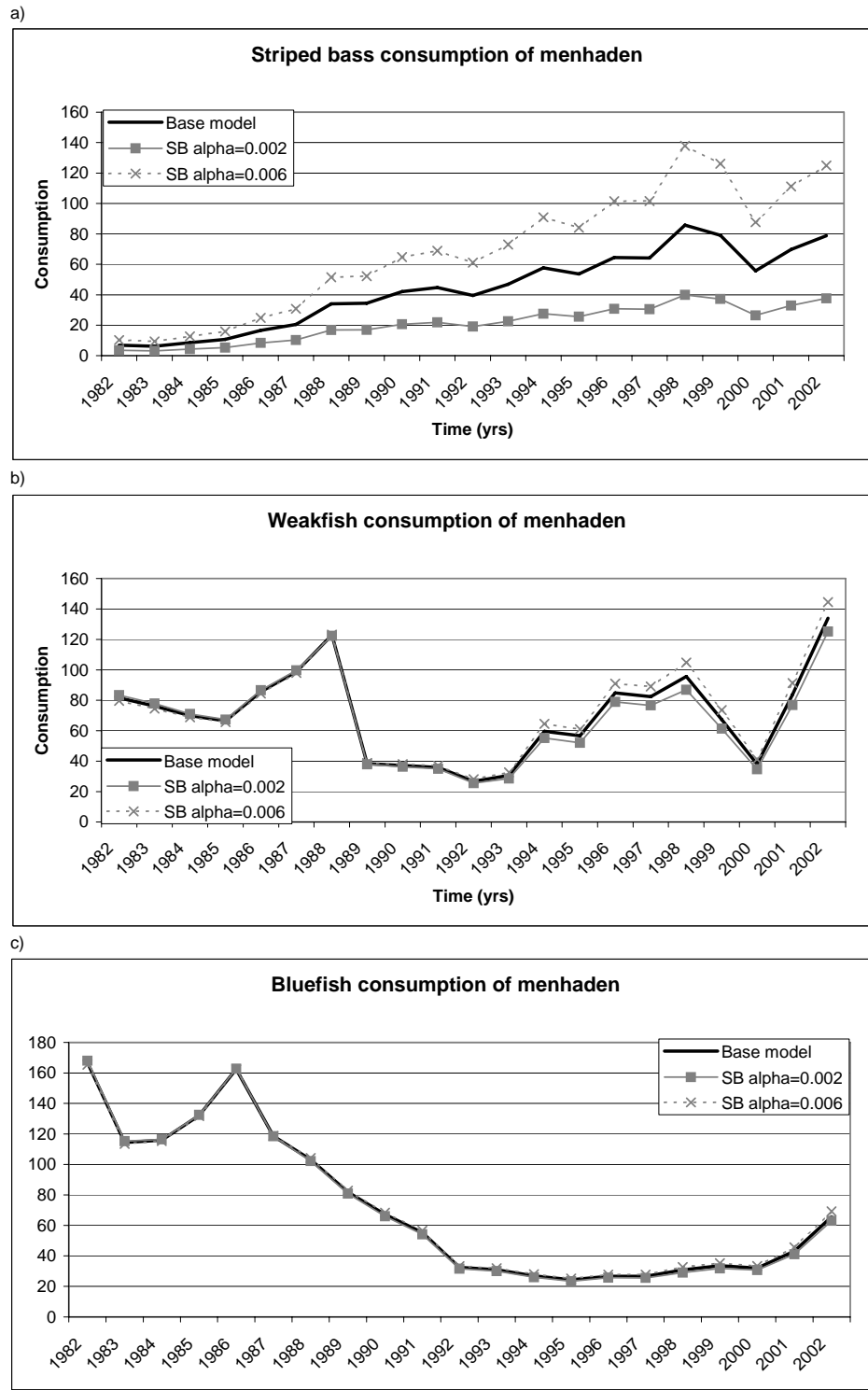


Figure D1.36. The affect of changing the gastric evacuation parameter α for weakfish on the consumption (000 mt) of a) striped bass, b) weakfish, and c) bluefish.

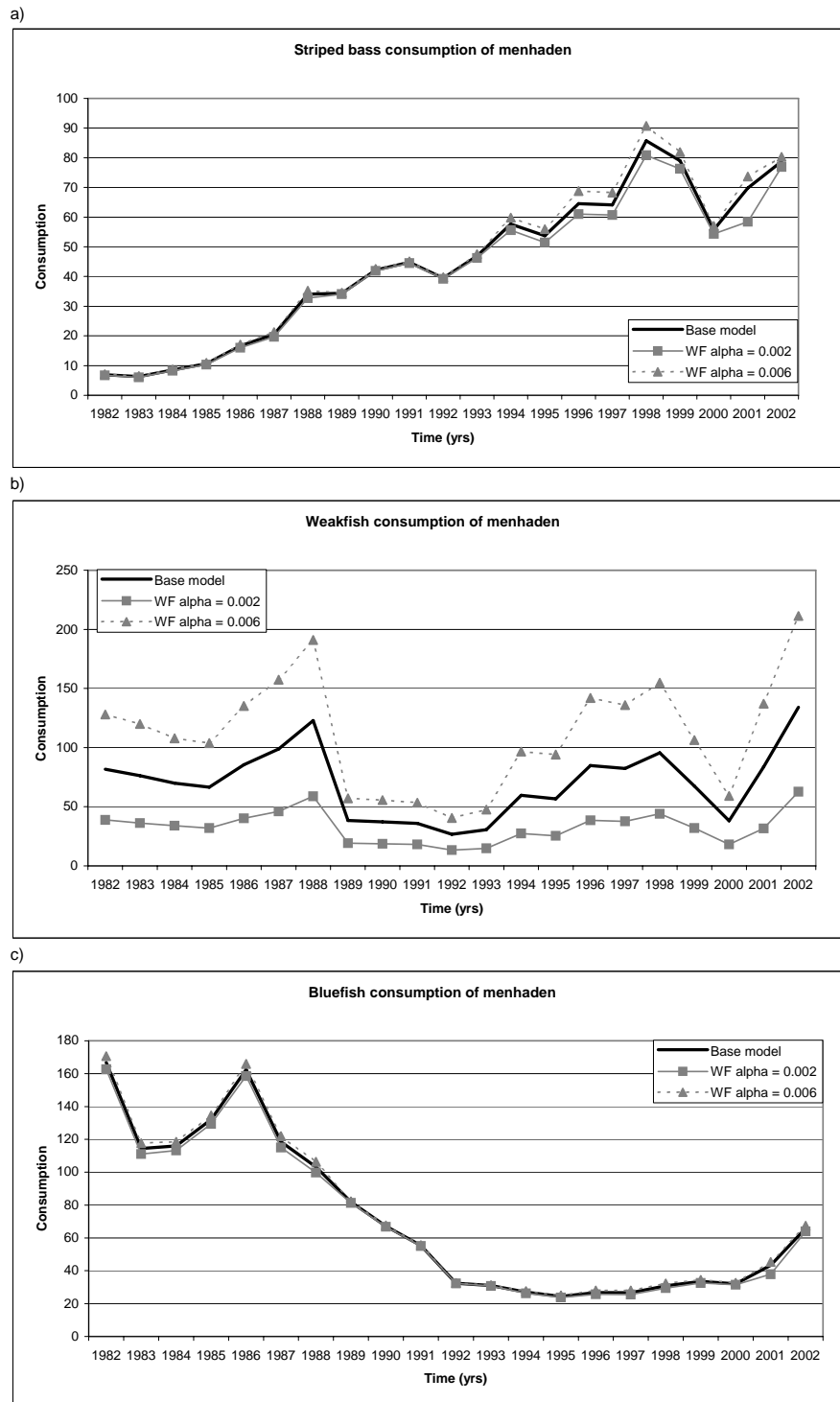


Figure D1.37. The affect of changing the gastric evacuation parameter α for bluefish on the consumption (000 mt) of a) striped bass, b) weakfish, and c) bluefish.

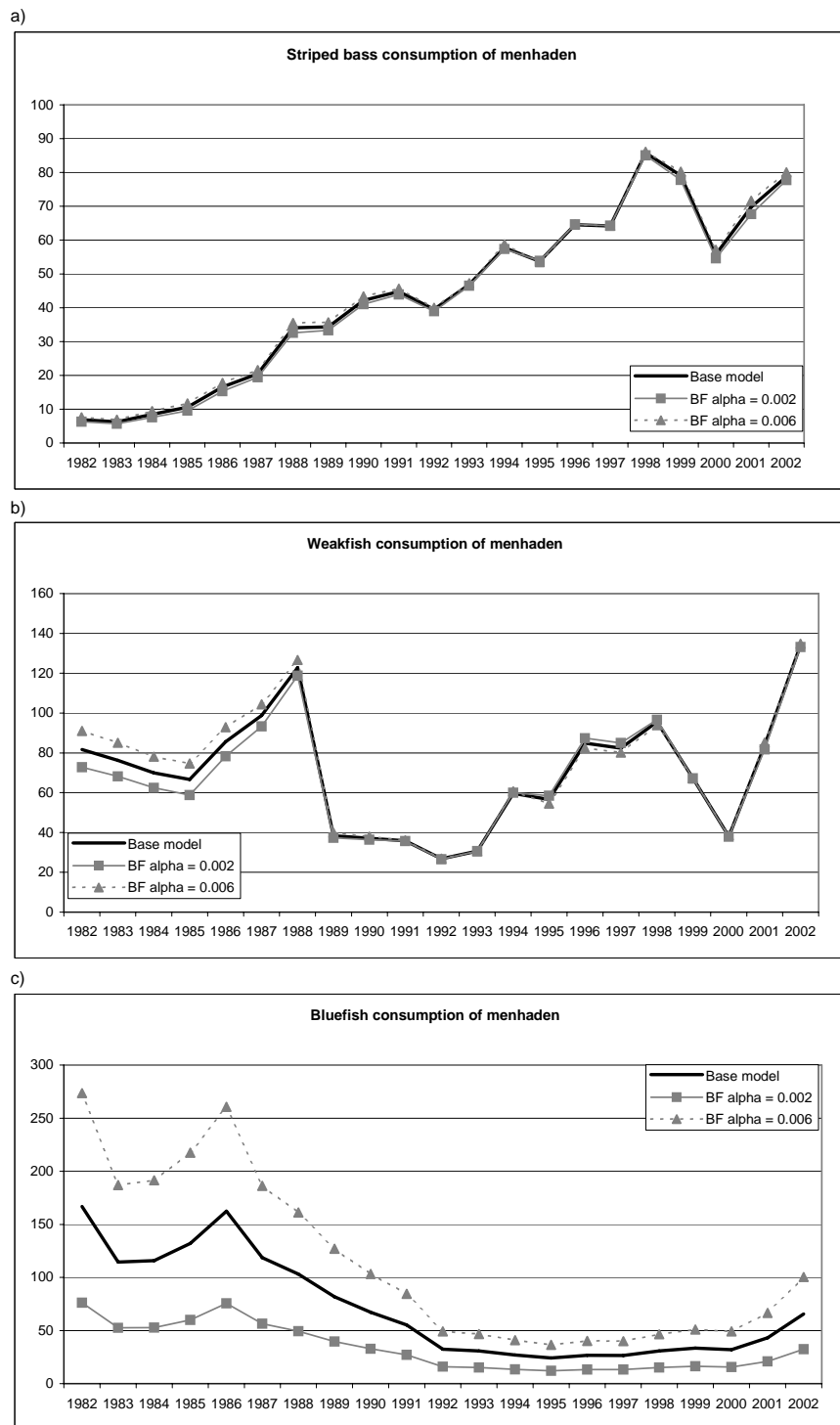


Figure D1.38. The affect of changing the gastric evacuation parameter β for weakfish on the consumption (000 mt) of a) striped bass, b) weakfish, and c) bluefish.

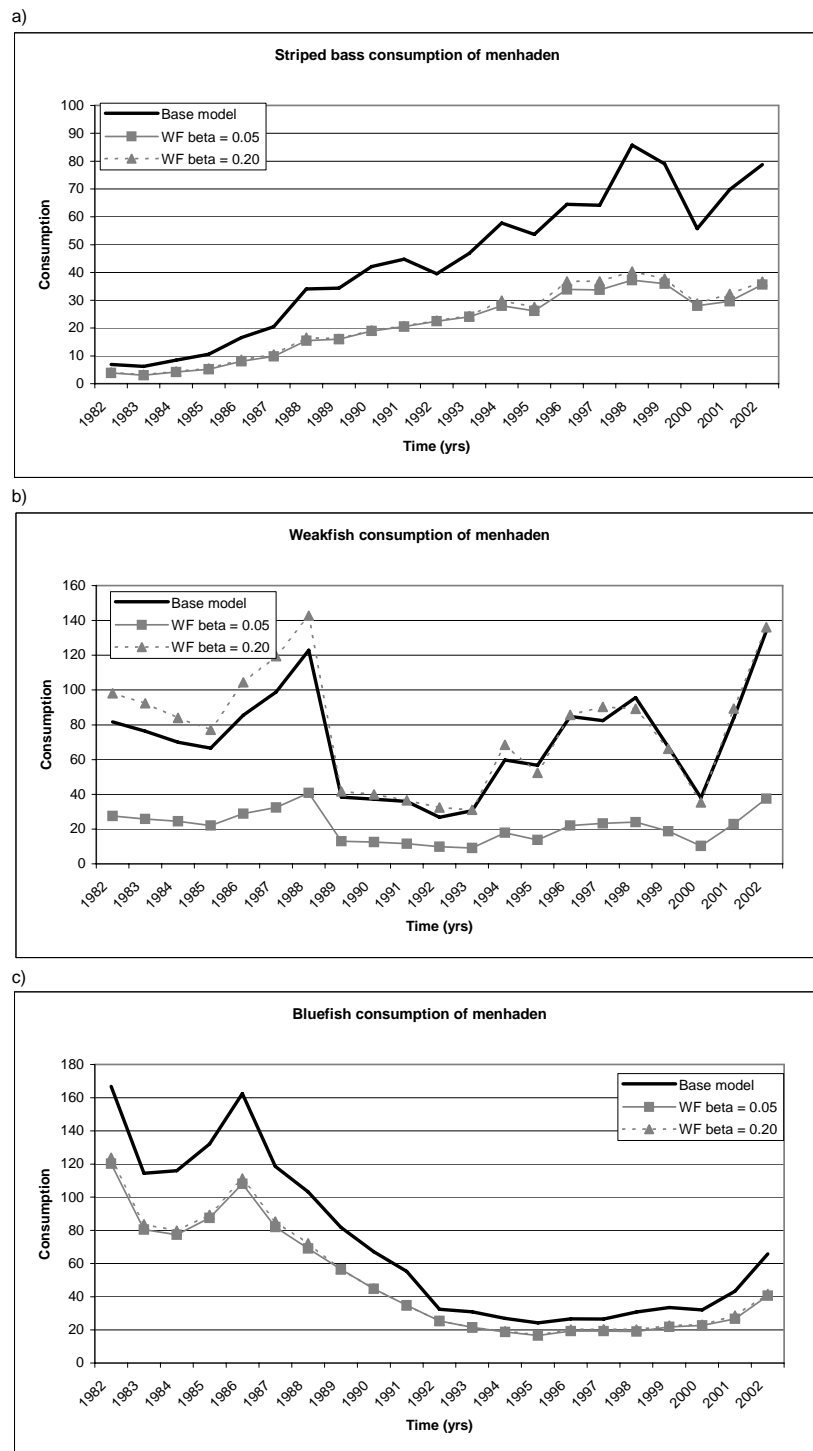


Figure D1.39. The affect of changing the gastric evacuation parameter β for bluefish on the consumption (000 mt) of a) striped bass, b) weakfish, and c) bluefish.

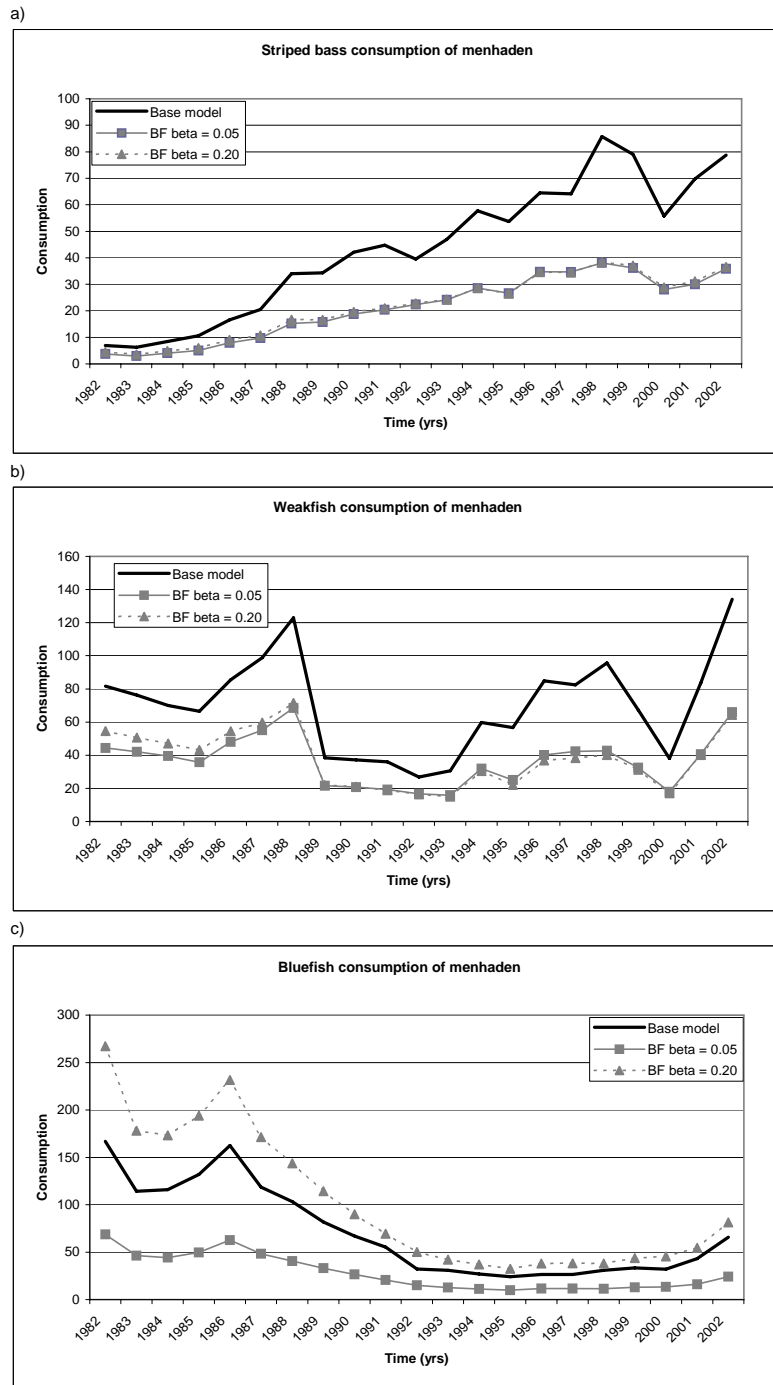


Figure D1.40. The affect of changing the gastric evacuation parameter β for striped bass on the consumption (000 mt) of a) striped bass, b) weakfish, and c) bluefish.

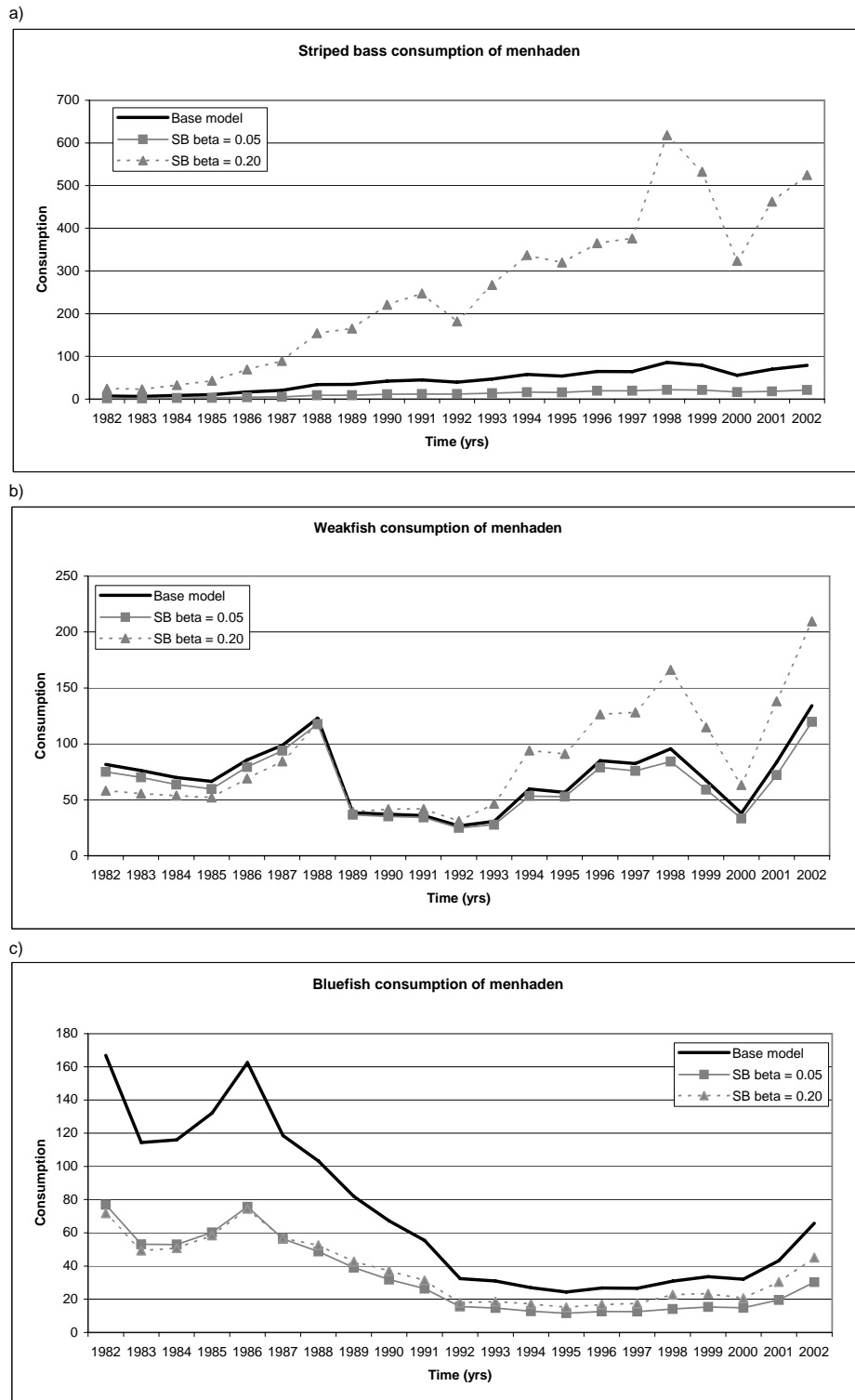


Figure D1.41. Comparison of predation mortality (M2) for age-0 menhaden with preference typed ranking all equal.

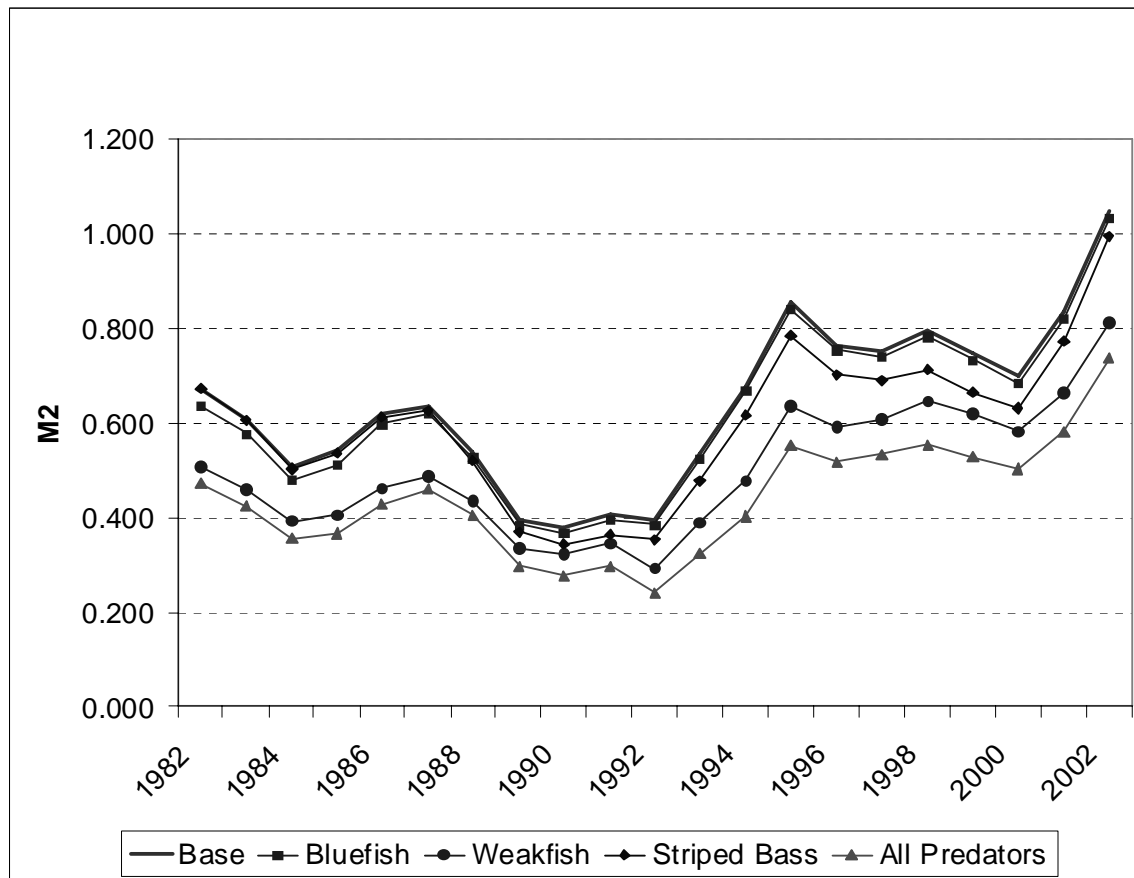


Figure D1.42. Comparison of predation mortality for age-0 menhaden with preference type ranking equal for fish and invertebrates.

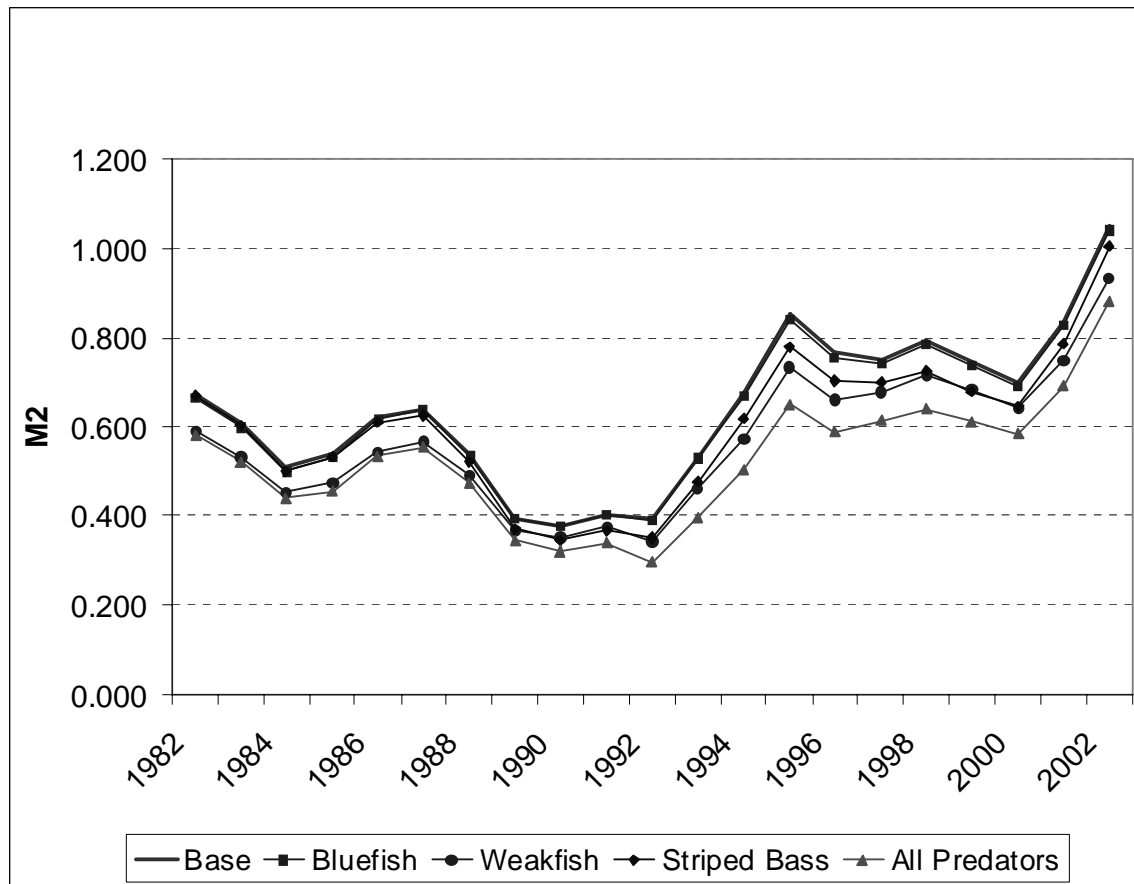


Figure D1.43. Comparison of predation mortality (M2) for age-1 menhaden with preference type ranking all equal.

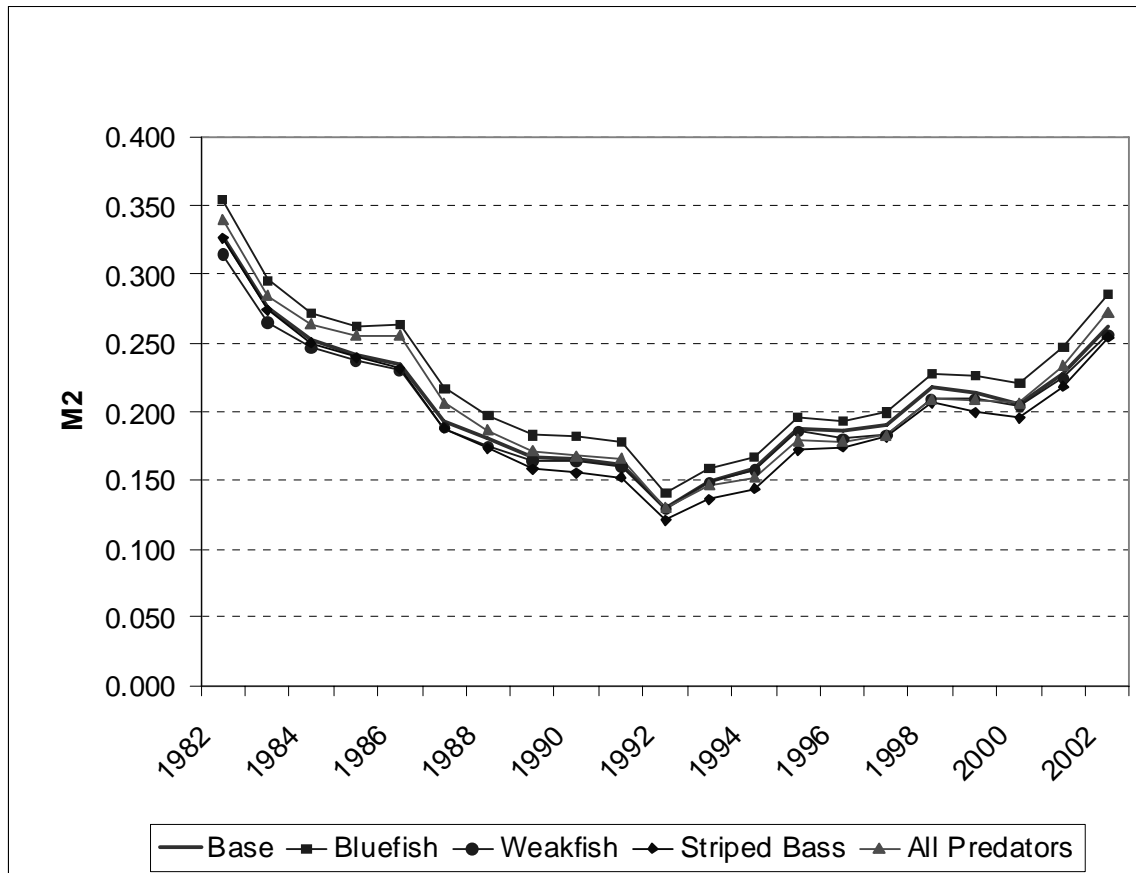


Figure D1.44. Comparison of predation mortality for age-1 menhaden with preference type ranking equal for fish and invertebrates.

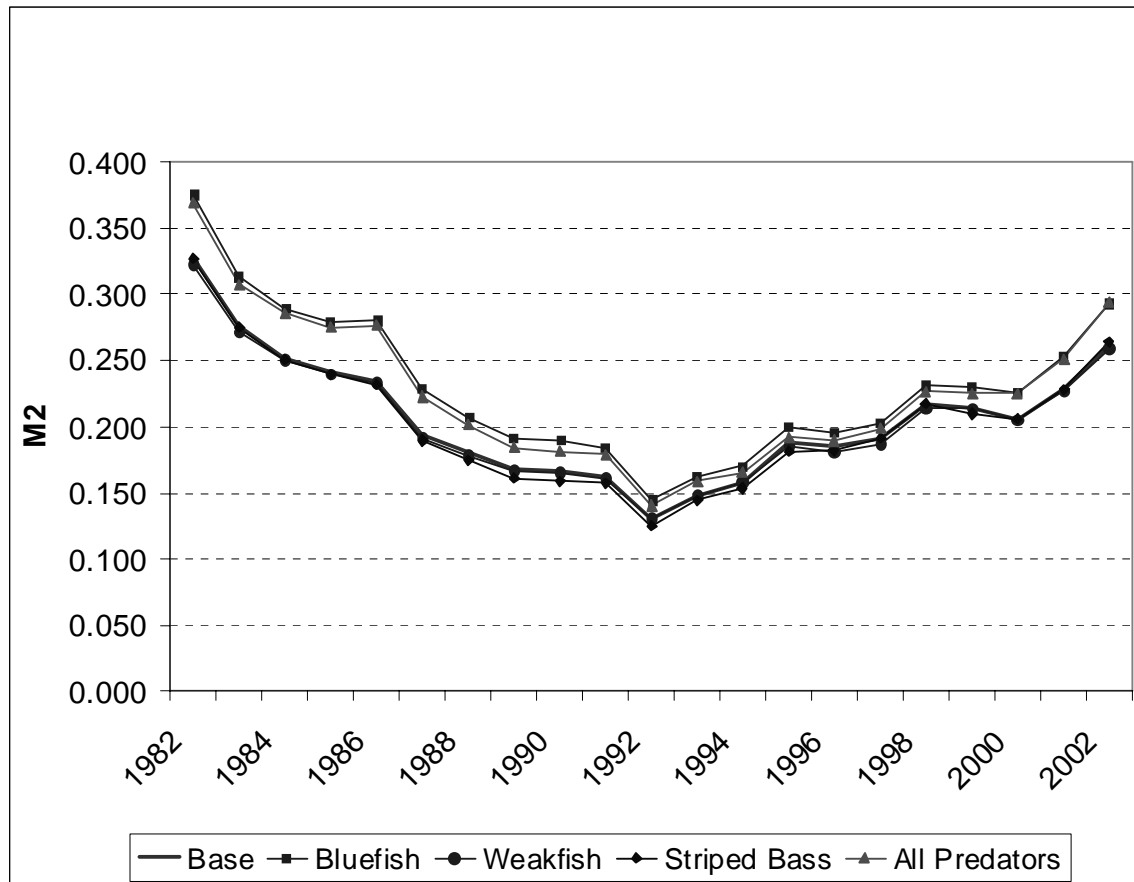


Figure D1.45. Comparison of predation mortality (M2) for age-2 menhaden with preference type ranking all equal.

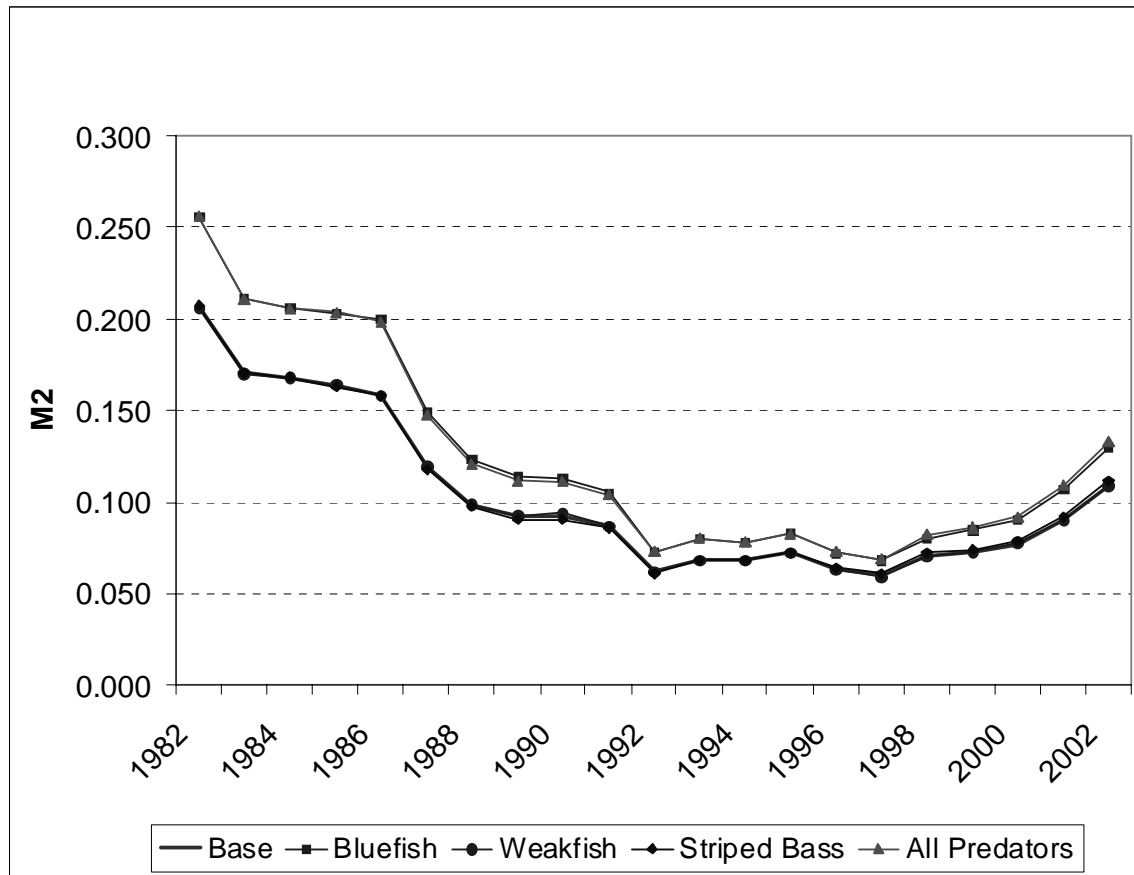


Figure D1.46. Comparison of predation mortality (M2) for age-2 menhaden with preference type ranking equal for fish and invertebrates.

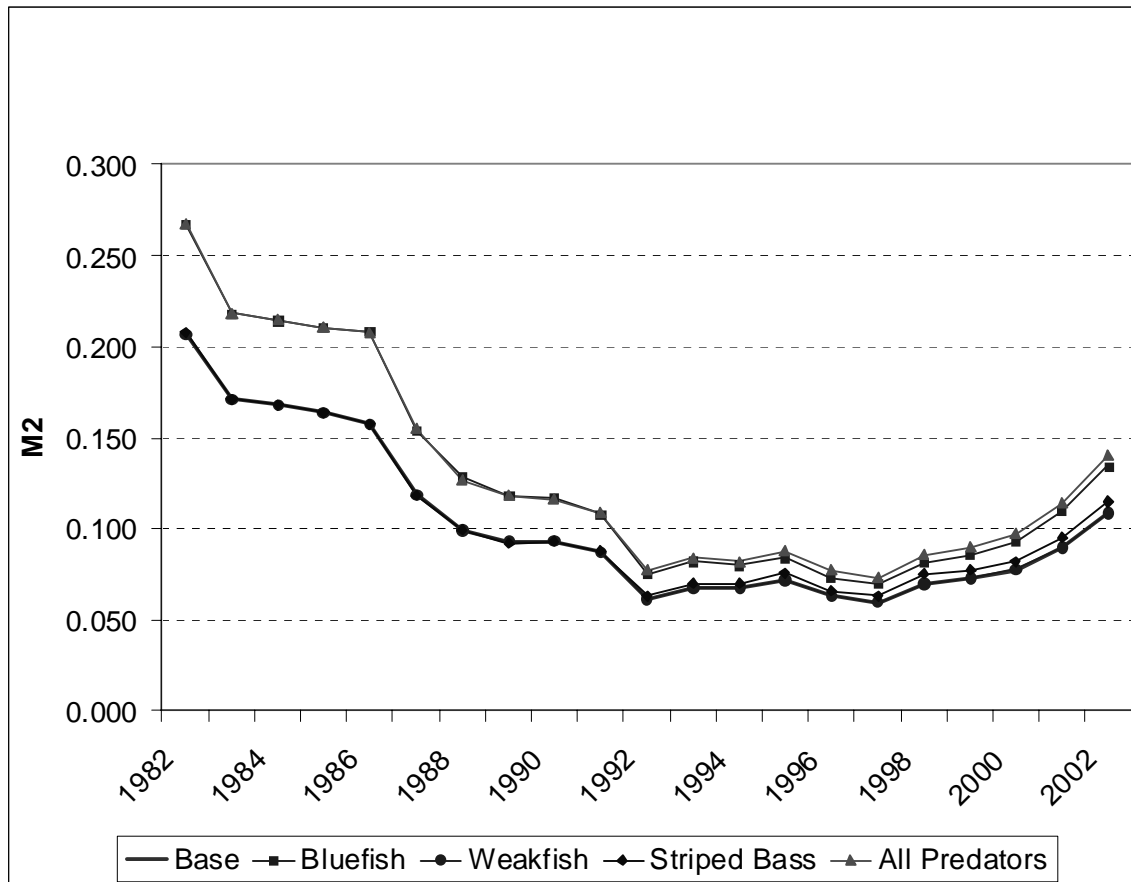


Figure D1.47. Comparison of average fishing mortality (F) for menhaden with preference type ranking all equal.

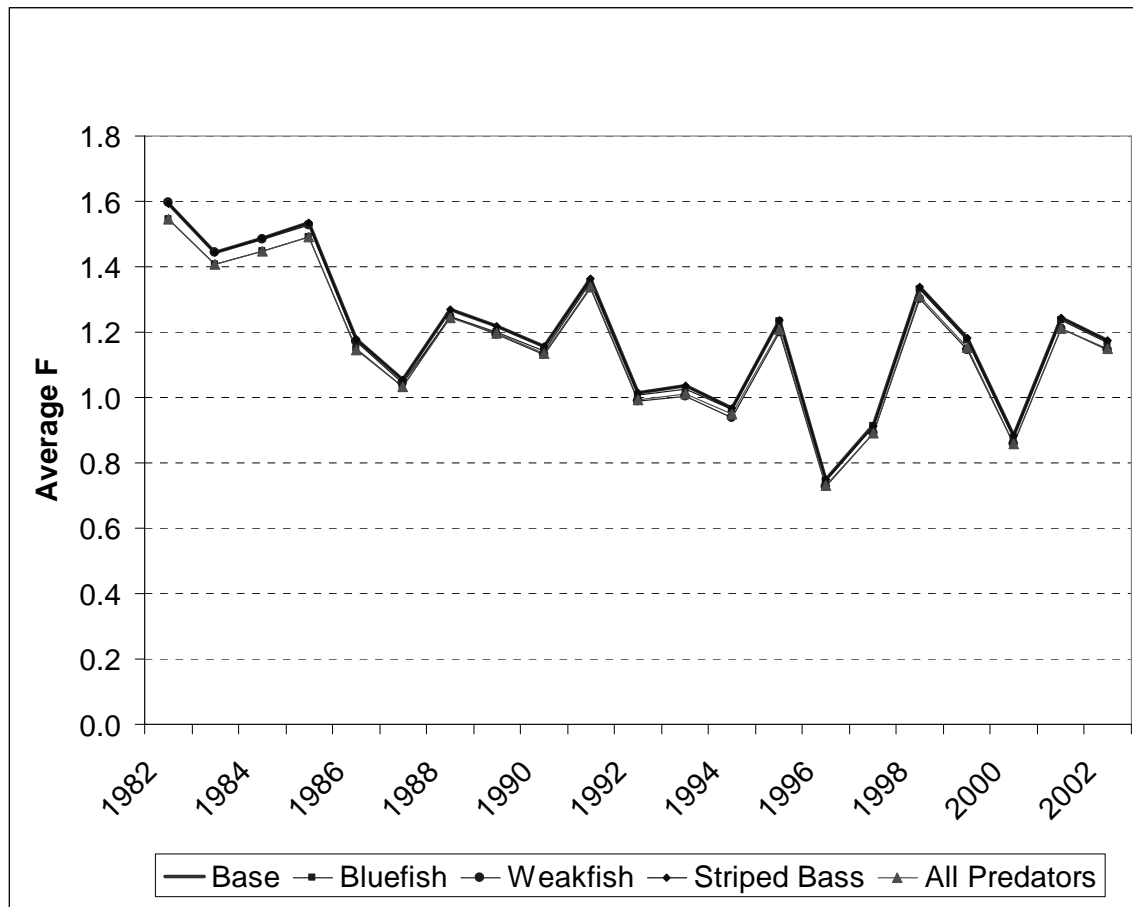


Figure D1.48. Comparison of average fishing mortality (F) for menhaden with preference type ranking equal for fish and invertebrates.

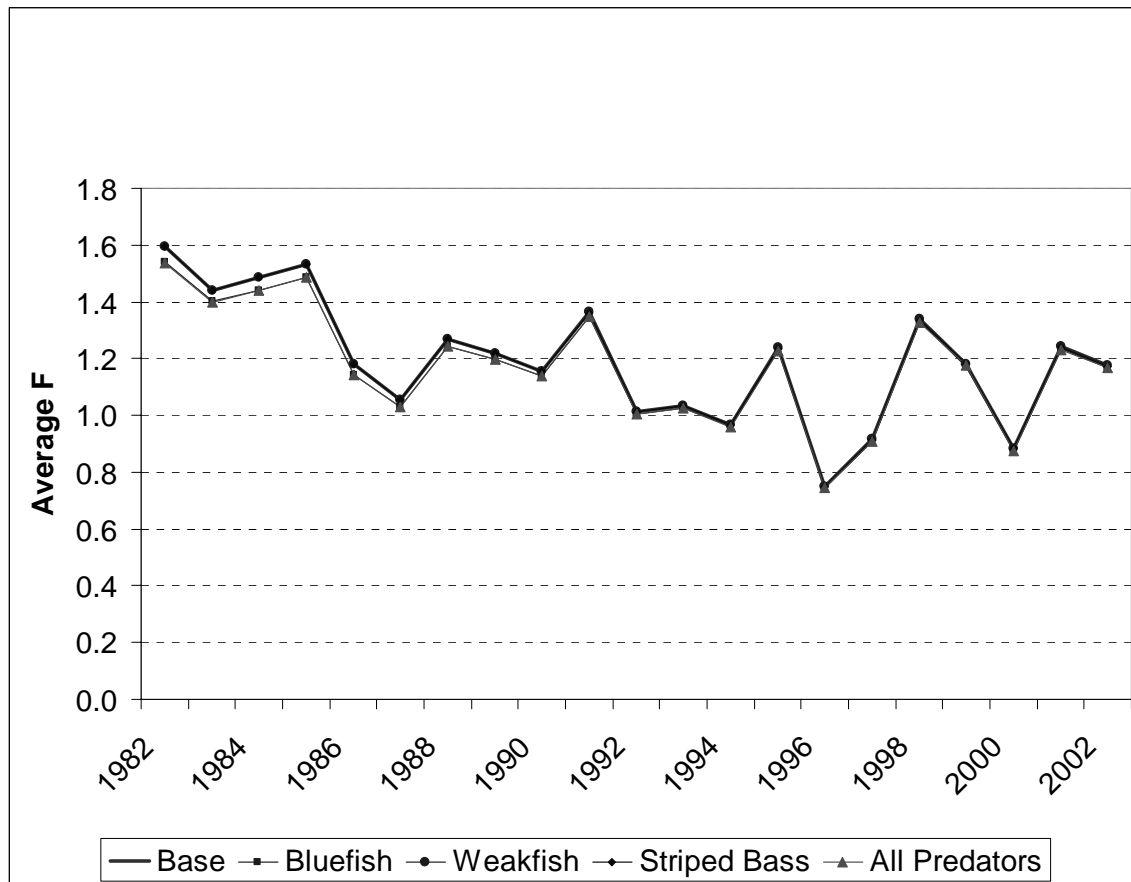


Figure D1.49. Comparison of abundance of age-0 menhaden with preference type ranking all equal.

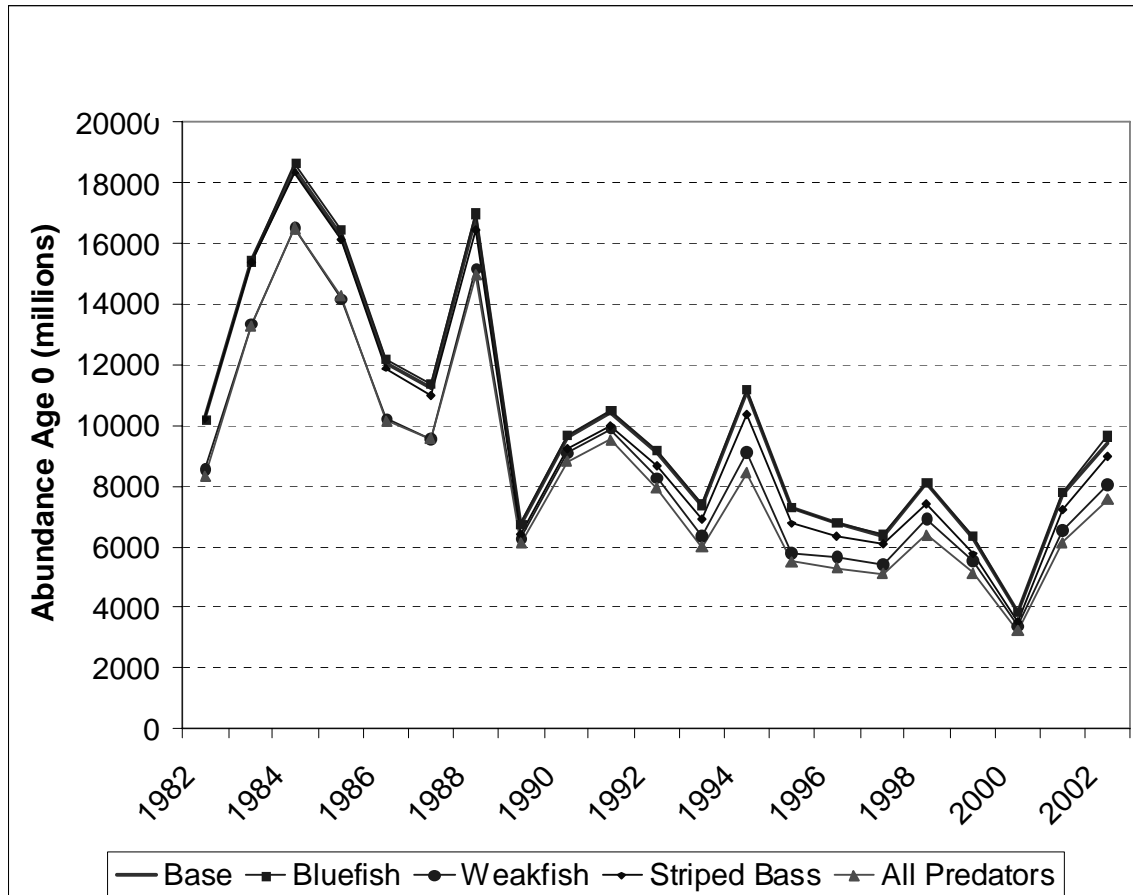


Figure D1.50. Comparison of abundance of age-0 menhaden with preference type ranking equal for fish and invertebrates.

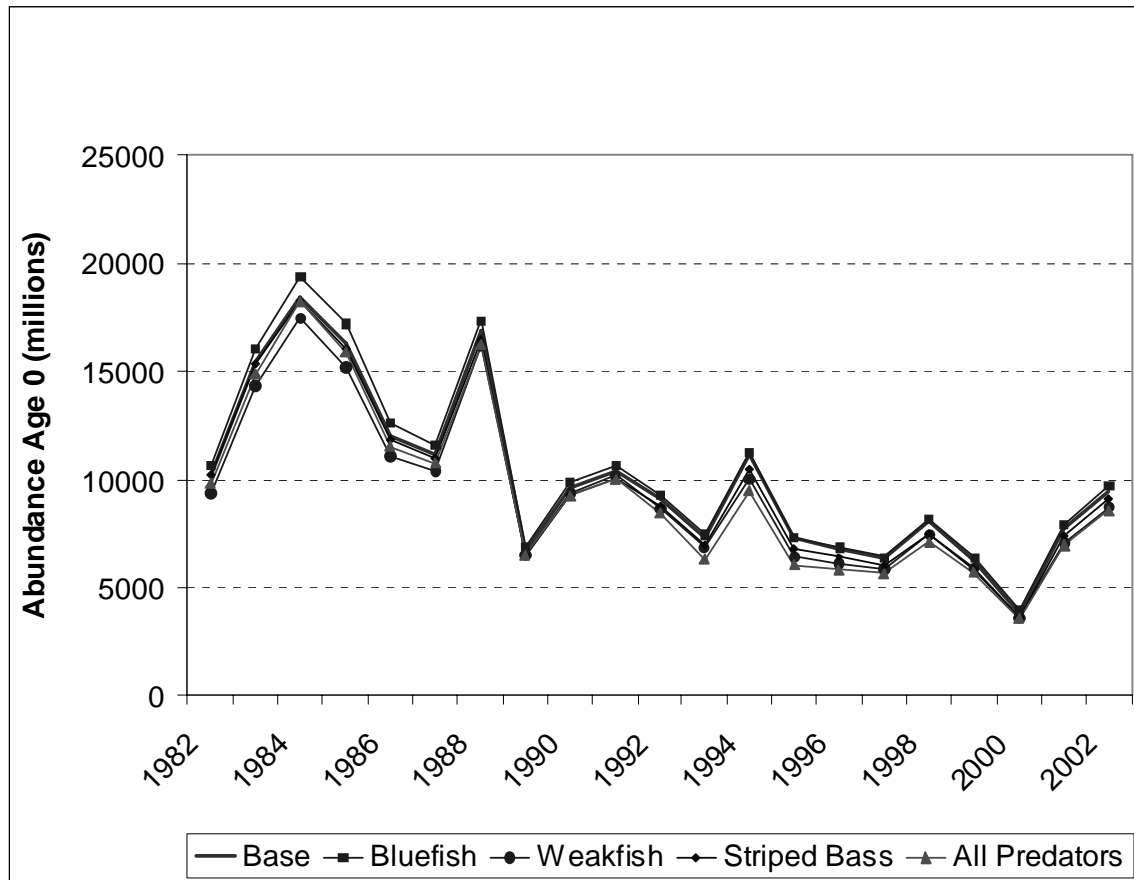


Figure D1.51. Comparison of abundance of age-1 menhaden with preference type ranking all equal.

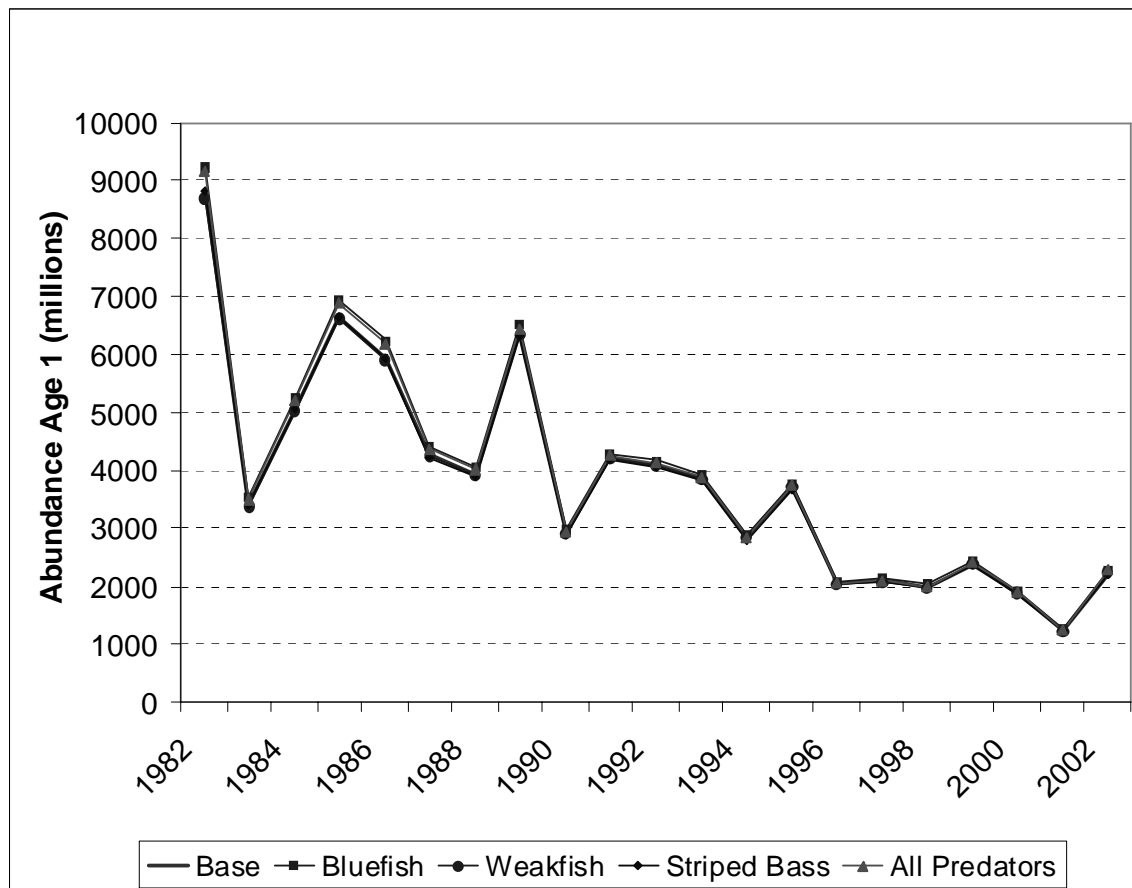


Figure D1.52. Comparison of abundance of age-1 menhaden with preference type ranking equal for fish and invertebrates.

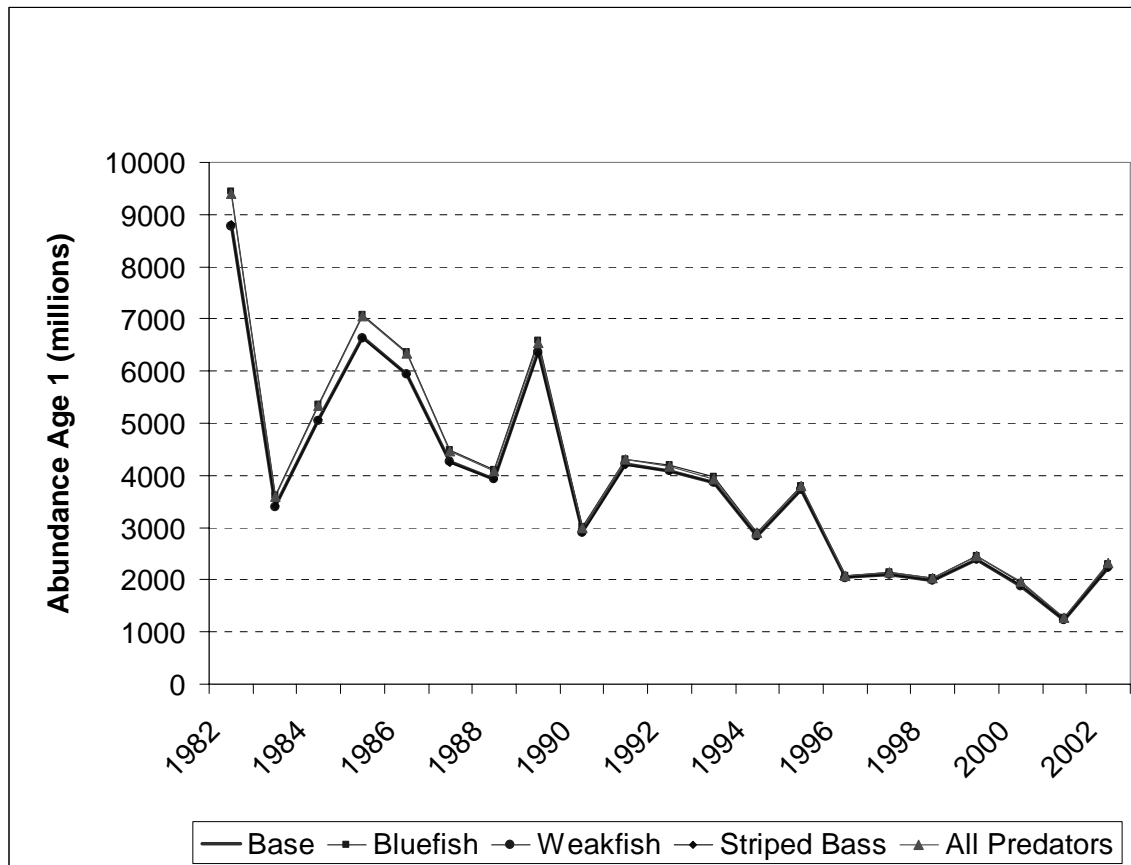


Figure D1.53. Comparison of menhaden spawning stock biomass (SSB) with preference type ranking all equal.

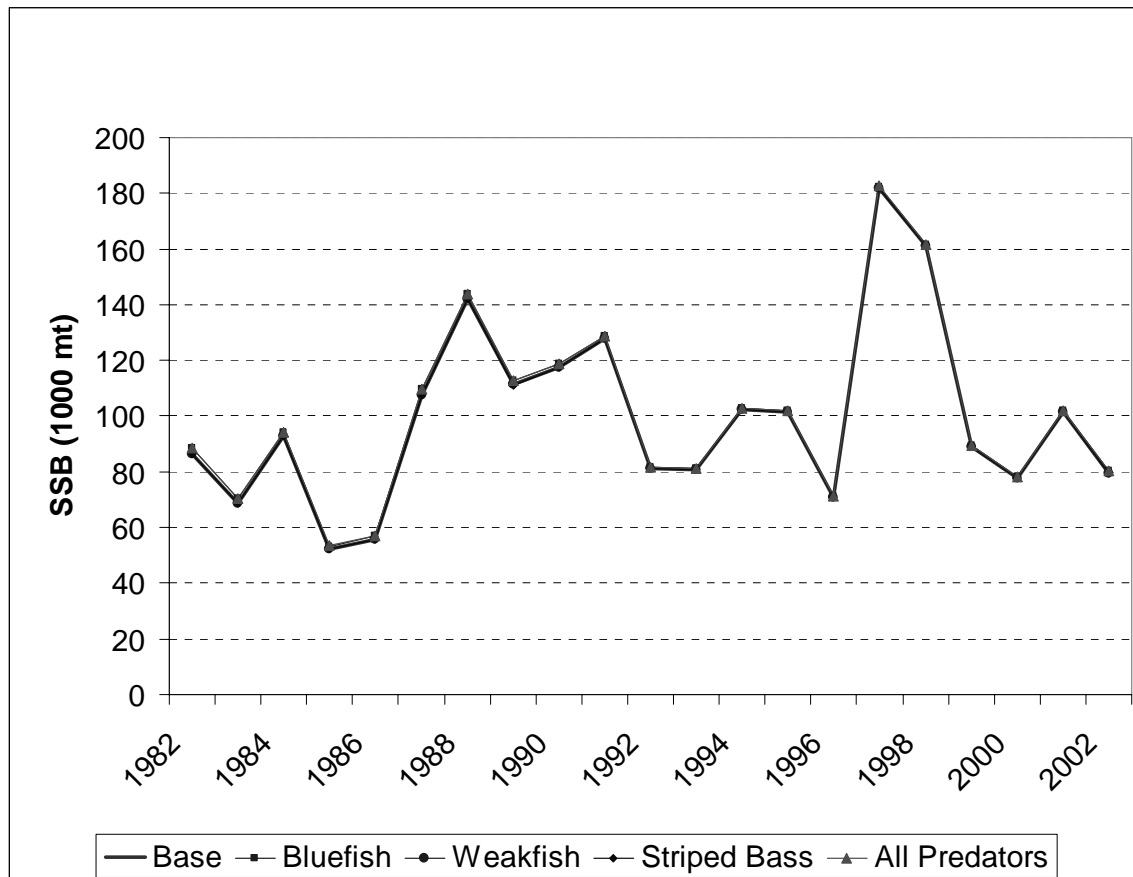


Figure D1.54. Comparison of menhaden spawning stock biomass (SSB) with preference type ranking equal for fish and invertebrates.

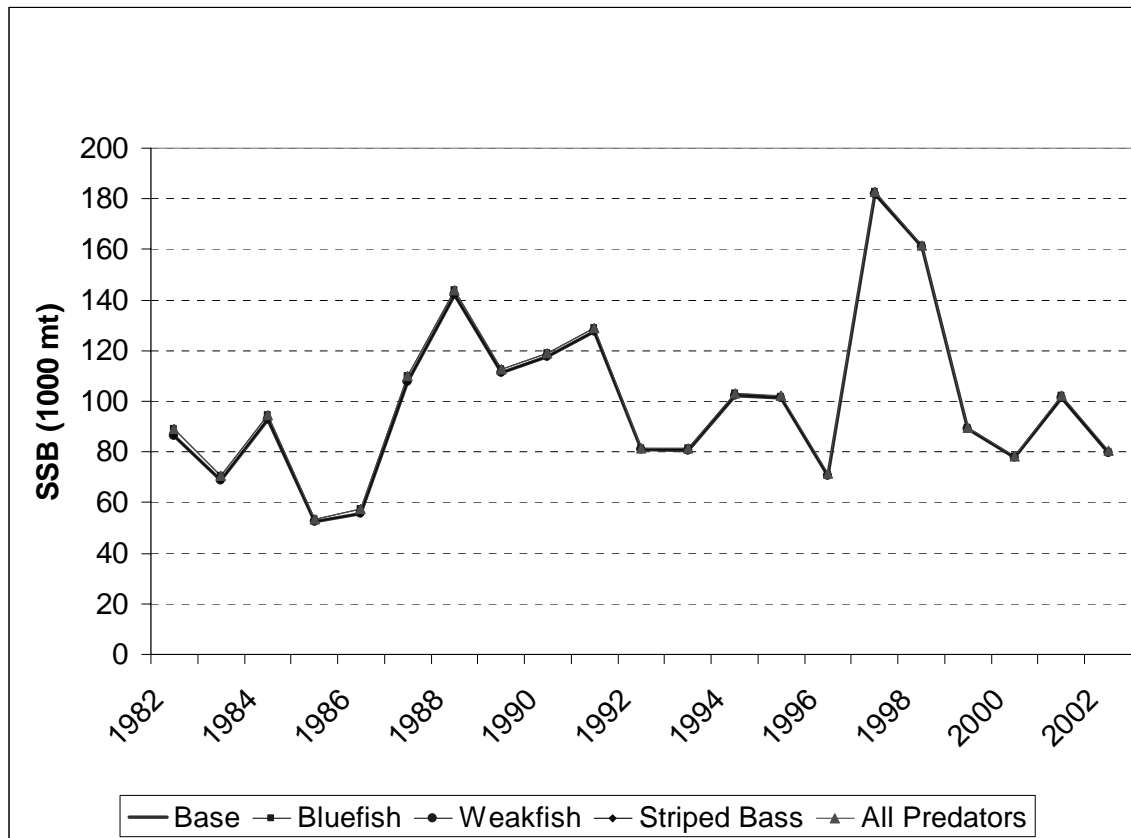


Figure D1.55. Menhaden in diet of striped bass (equal weighting).

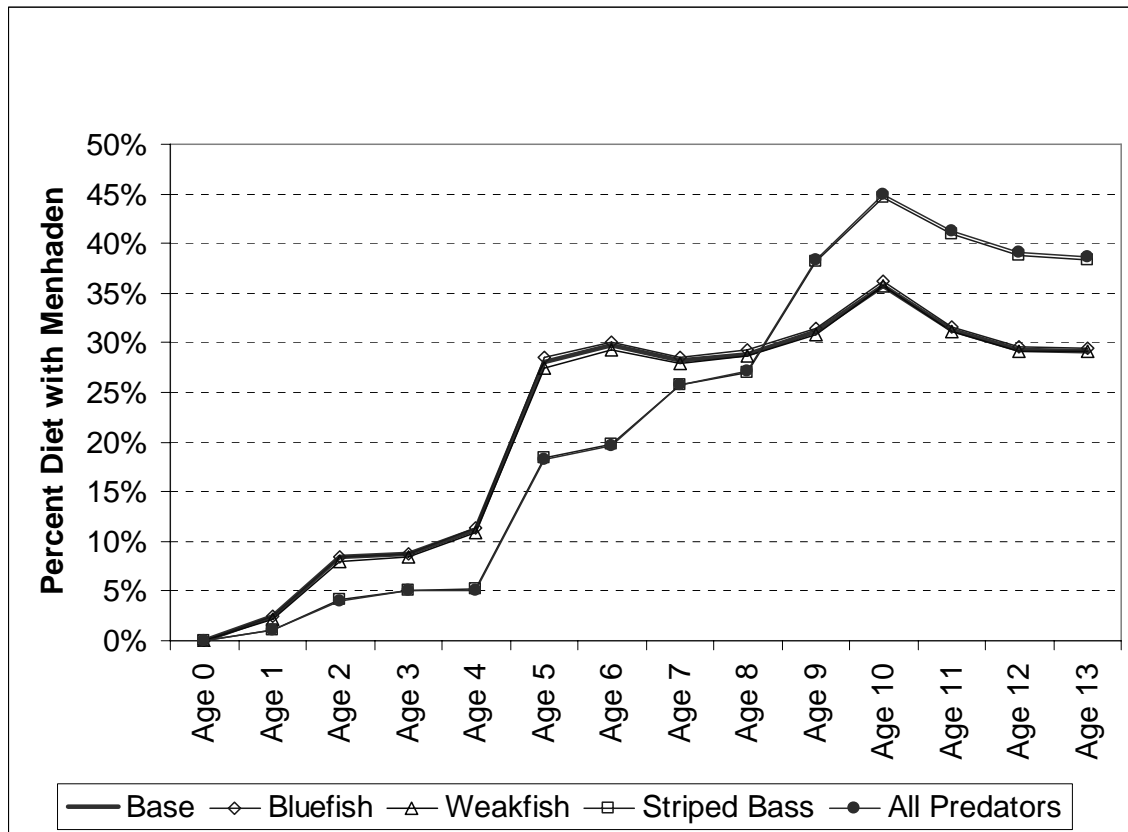


Figure D1.56. Menhaden in diet of striped bass (fish and invertebrate equal weighting).

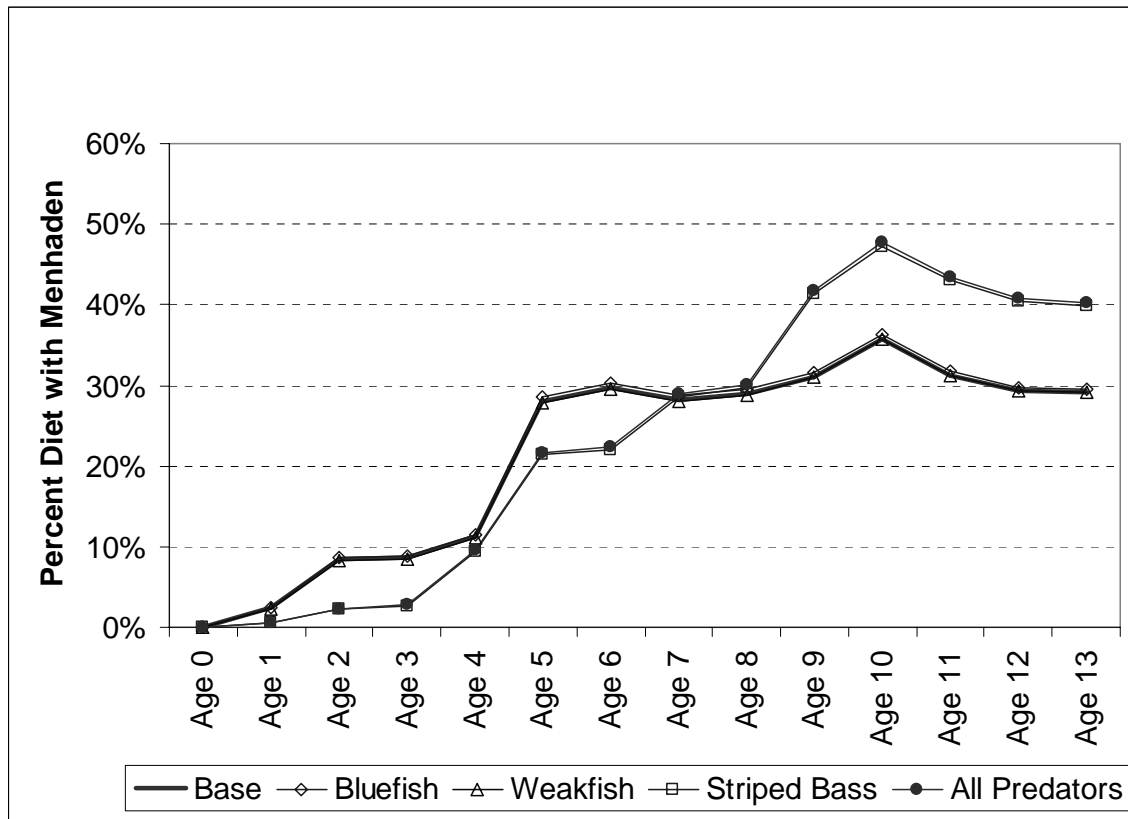


Figure D1.57. Menhaden in diet of weakfish (equal weighting).

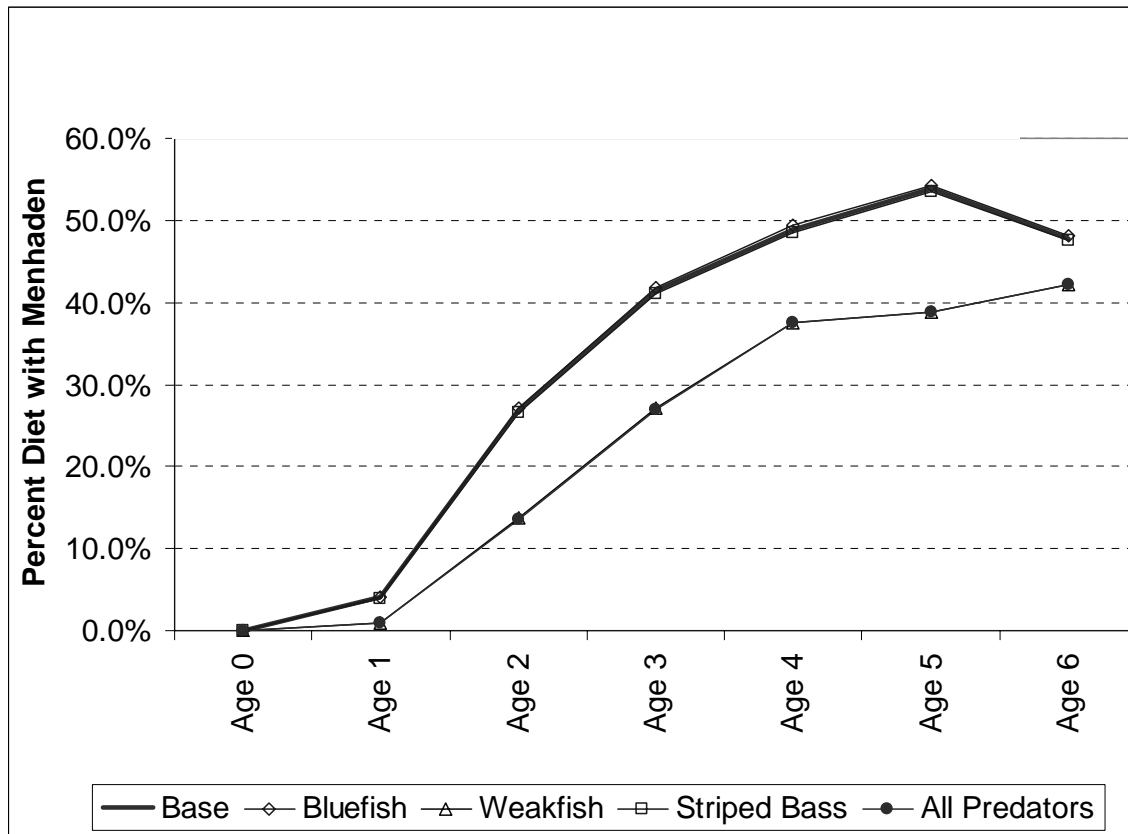


Figure D1.58. Menhaden in diet of weakfish (fish and invertebrate equal weighting).

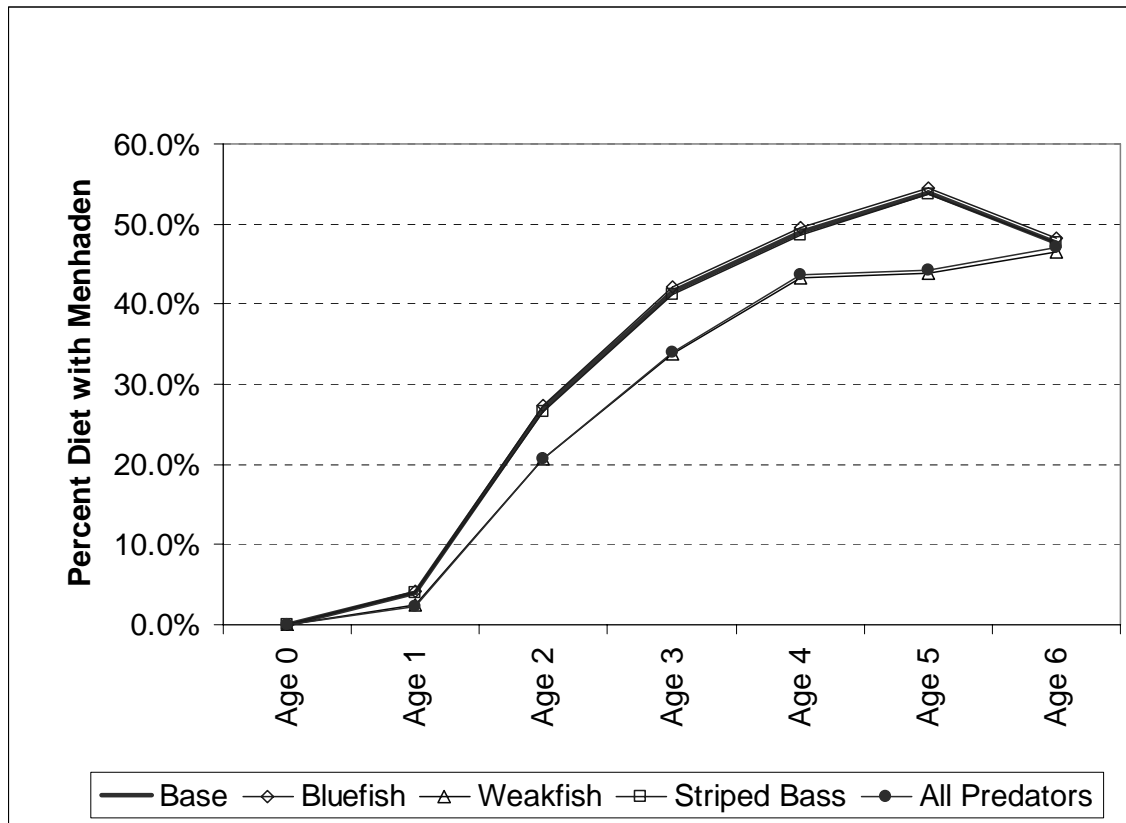


Figure D1.59. Menhaden in diet of bluefish (equal weighting).

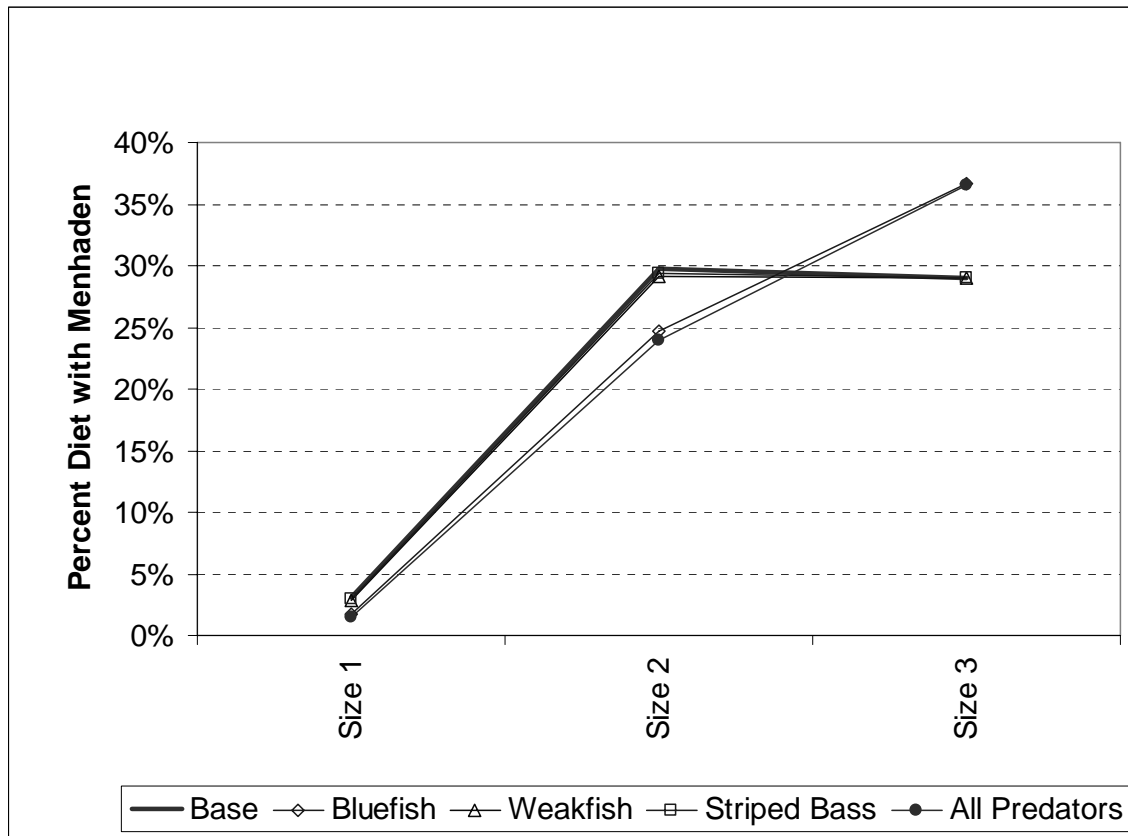


Figure D1.60. Menhaden in diet of bluefish (fish and invertebrate equal weighting).

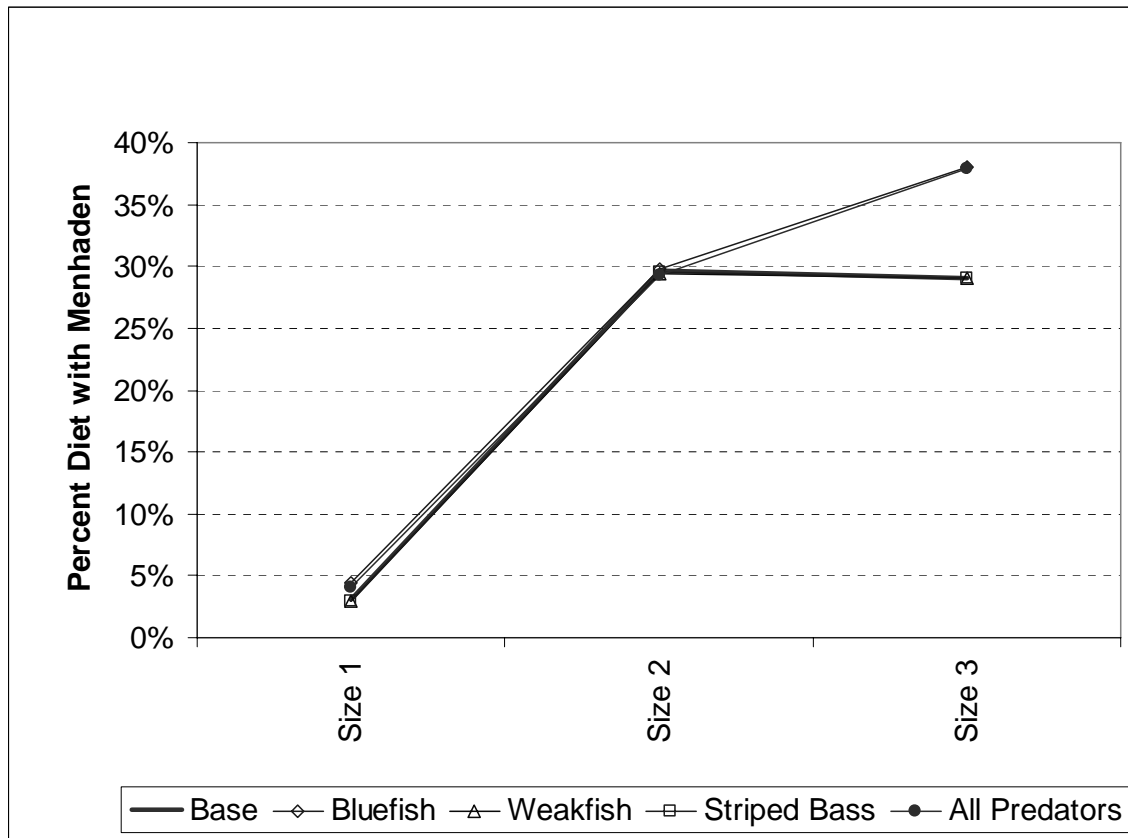


Figure D1.61. Consumption of menhaden by striped bass (equal preferences).

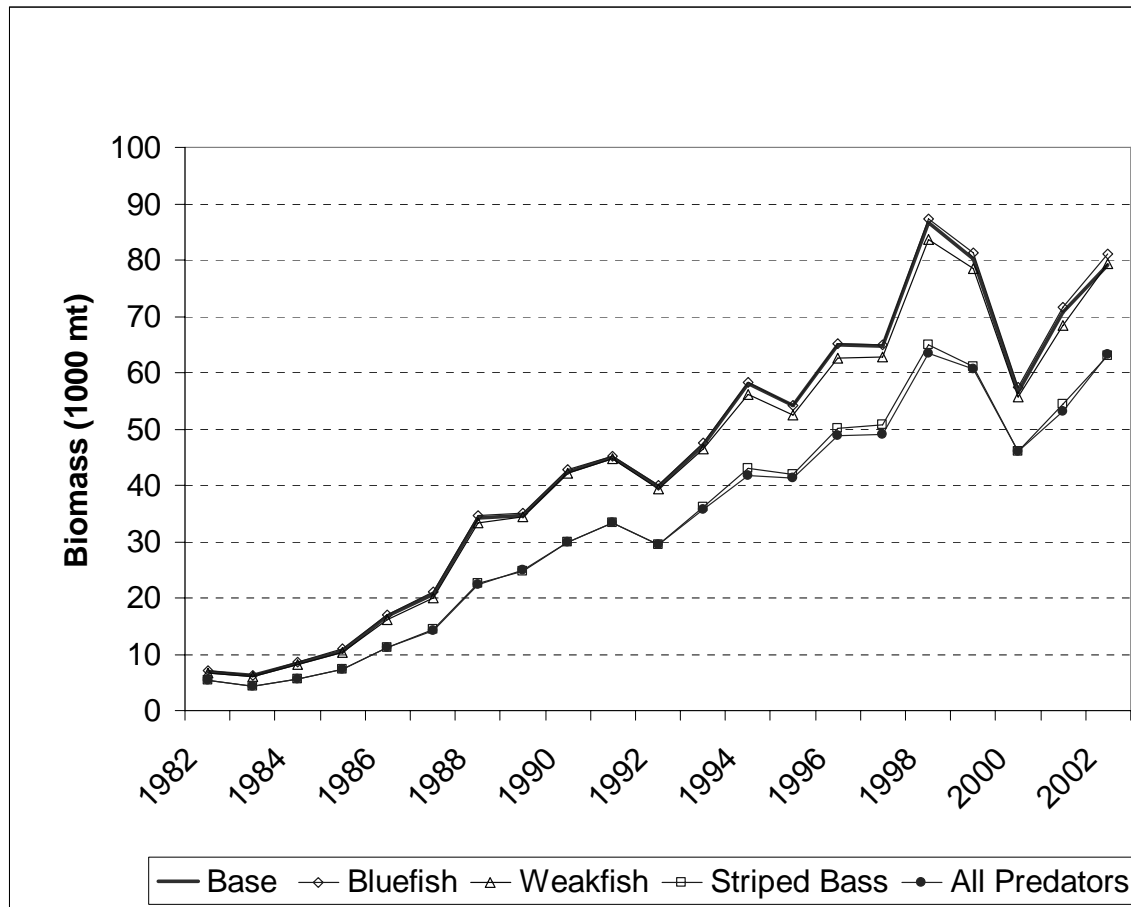


Figure D1.62. Consumption of menhaden by striped bass (fish and invertebrates equal preferences).

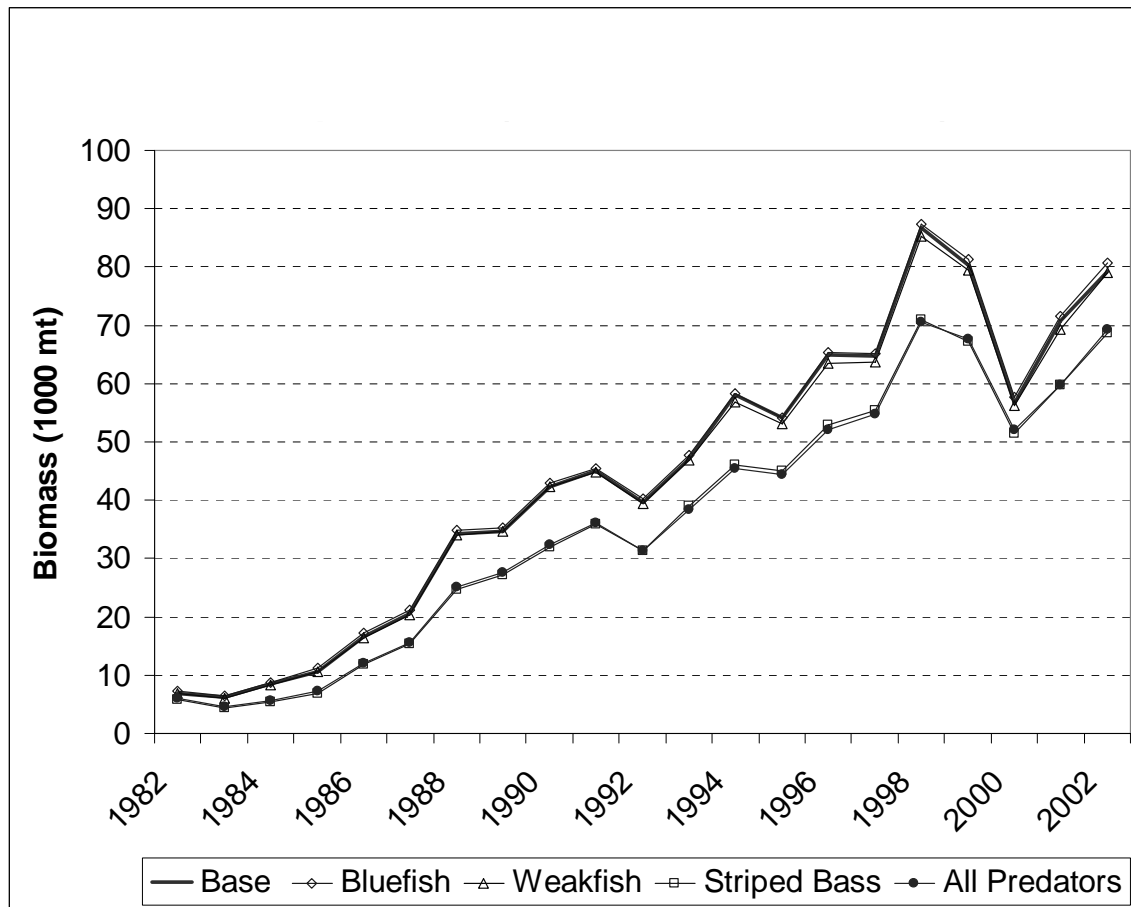


Figure D1.63. Consumption of menhaden by weakfish (equal preferences).

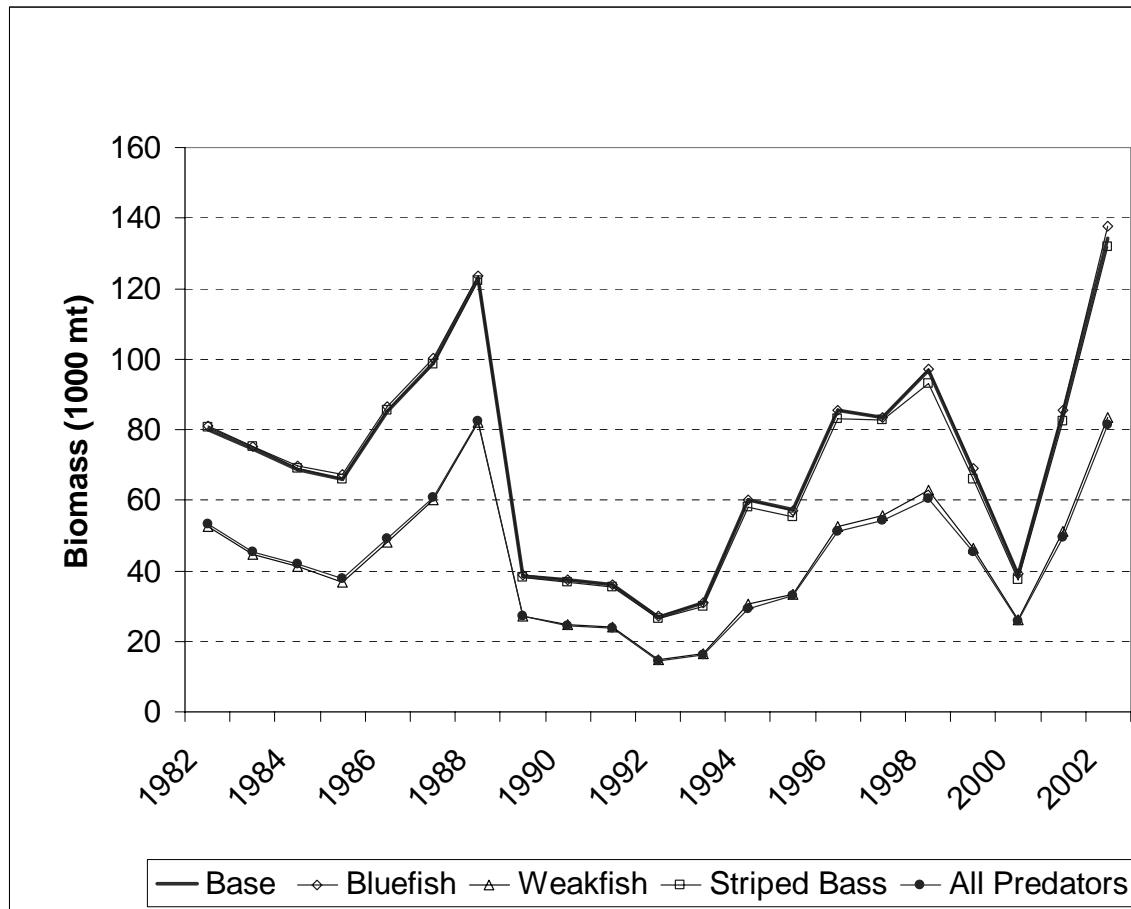


Figure D1.64. Consumption of menhaden by weakfish (fish and invertebrates equal preferences).

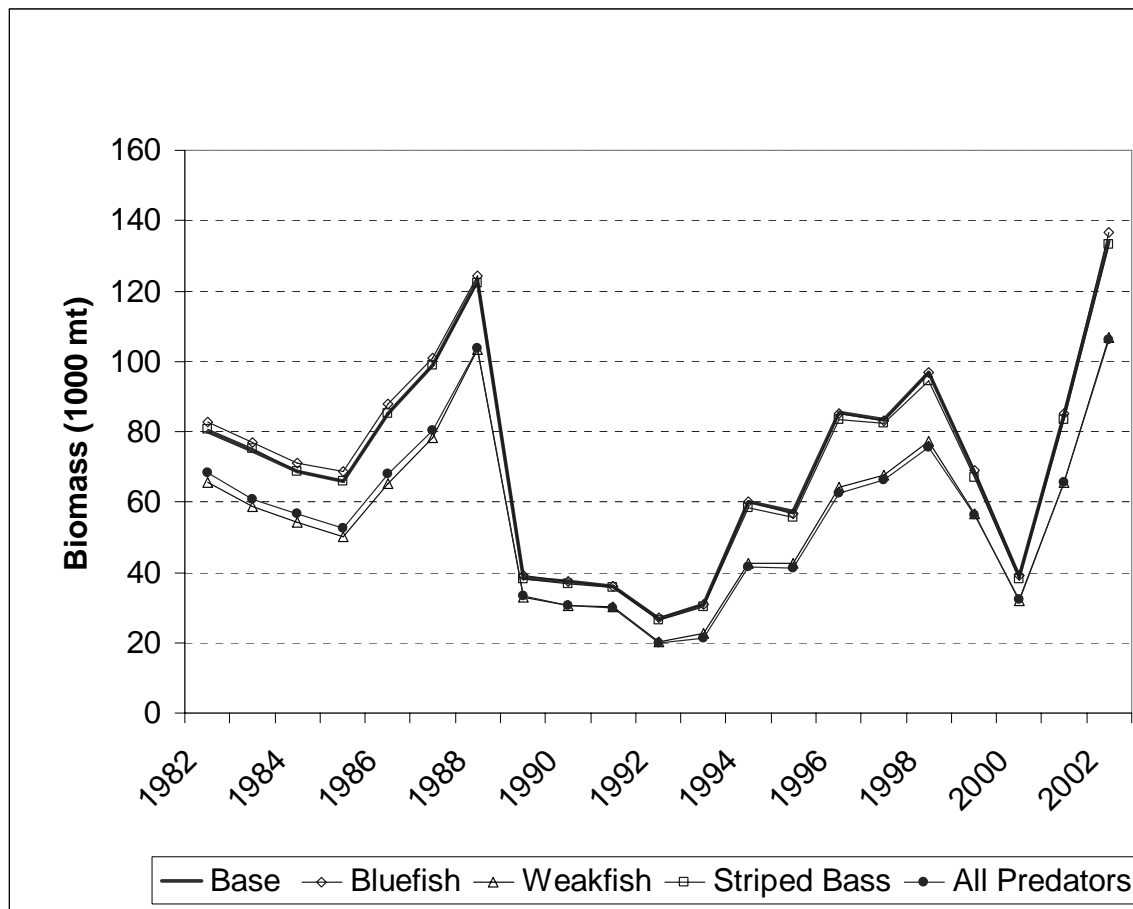


Figure D1.65. Consumption of menhaden by bluefish (equal preferences).

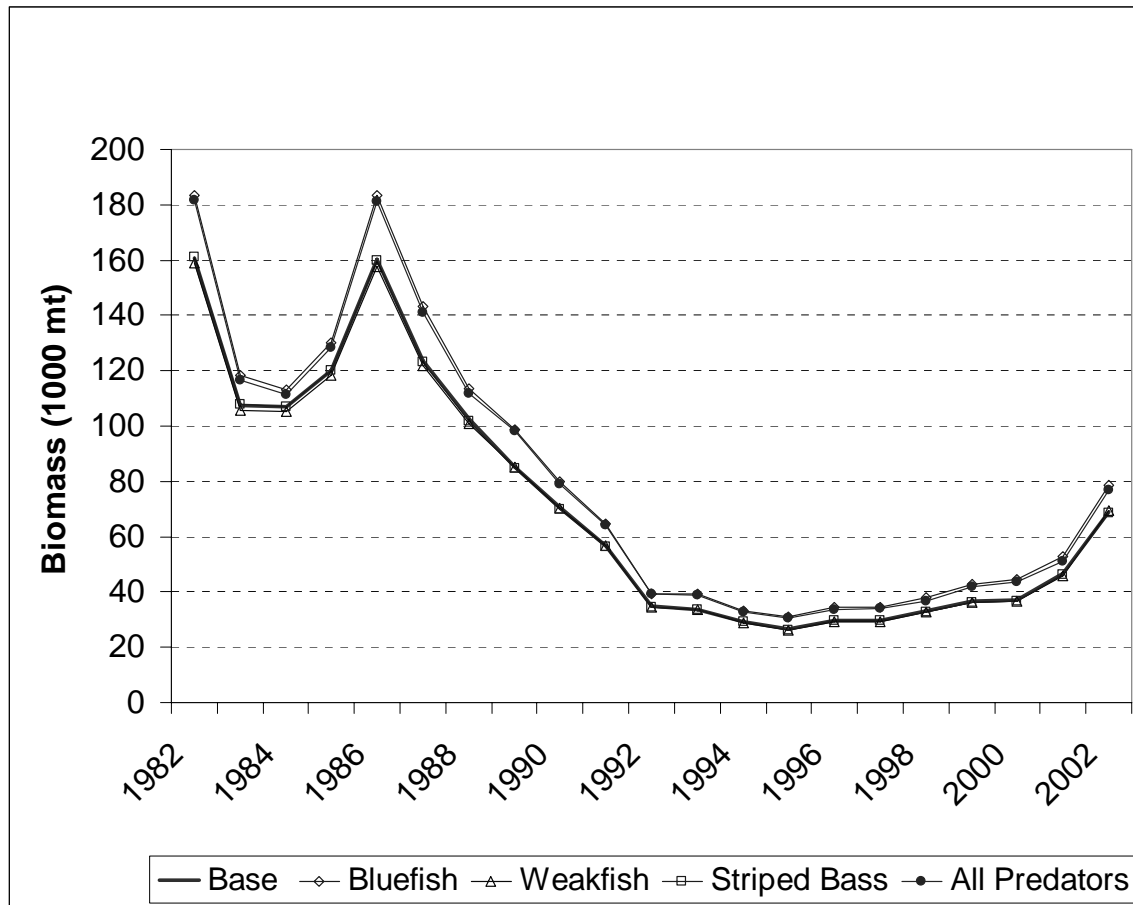


Figure D1.66. Consumption of menhaden by bluefish (fish and invertebrates equal preferences).

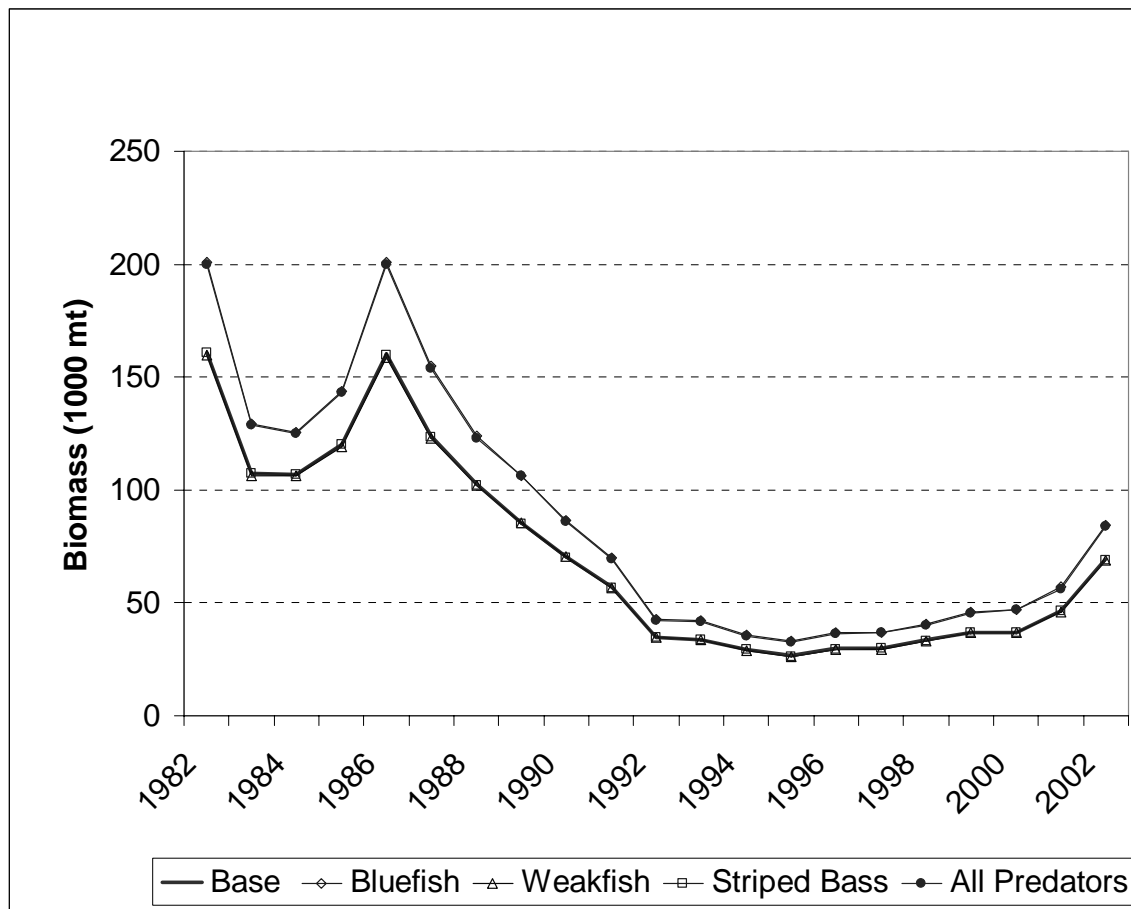


Figure D1.67. Total consumption (000 mt) of prey by striped bass for the base run configuration, which employed average weight-at-age over time and the alternate run employing the observed or variable weight-at-age over time.

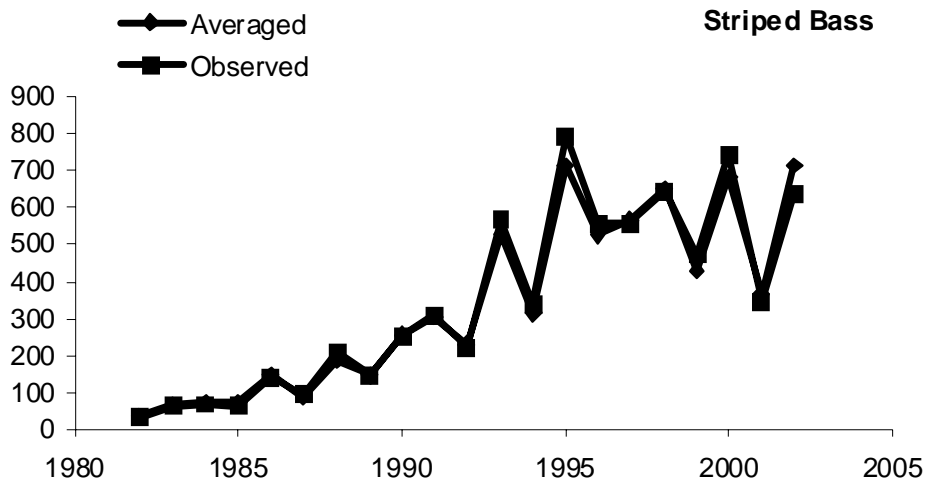


Figure D1.68. Total consumption (000 mt) of prey by weakfish for the base run configuration, which employed average weight-at-age over time and the alternate run employing the observed or variable weight-at-age over time.

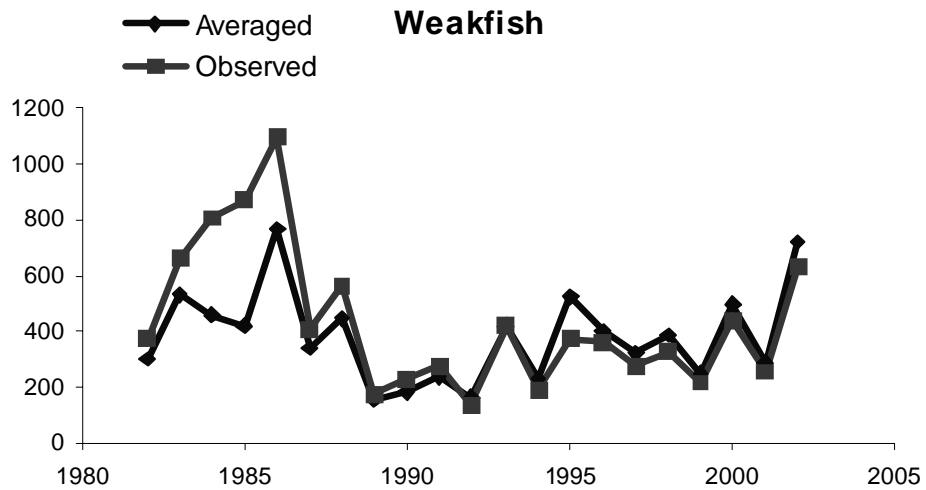


Figure D1.69. Total consumption (000 mt) of menhaden by striped bass for the base run configuration, which employed average weight-at-age over time and the alternate run employing the observed or variable weight-at-age over time.

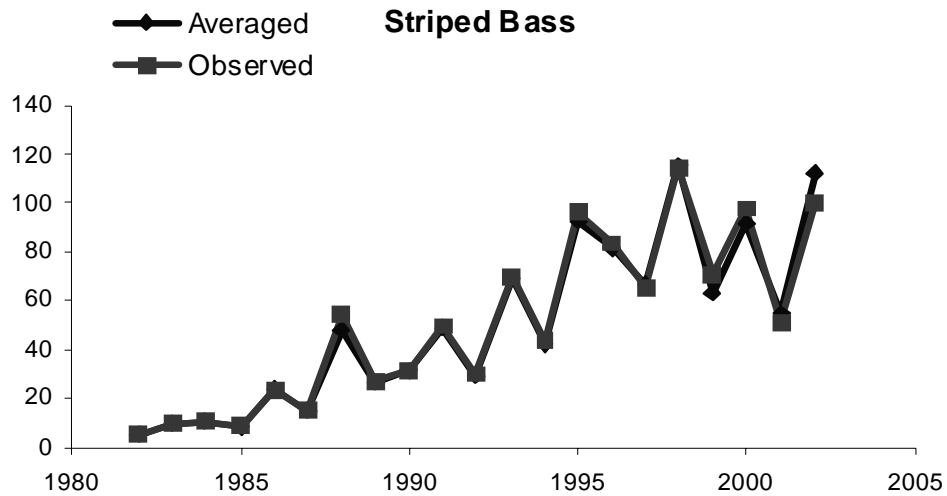


Figure D1.70. Total consumption (000 mt) of menhaden by weakfish for the base run configuration, which employed average weight-at-age over time and the alternate run employing the observed or variable weight-at-age over time.

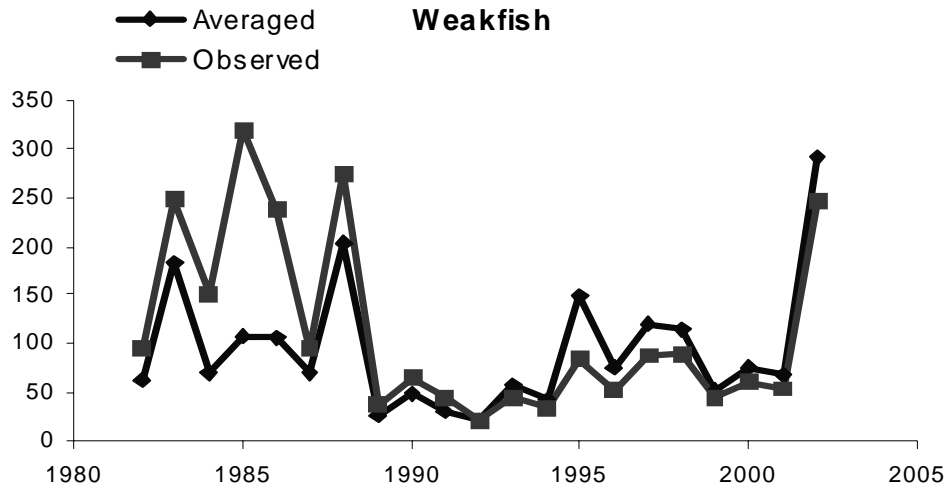


Figure D1.71. Predation mortality (M2) of menhaden by striped bass calculated based on variable (observed) weight-at-age and based on constant weight-at-age.

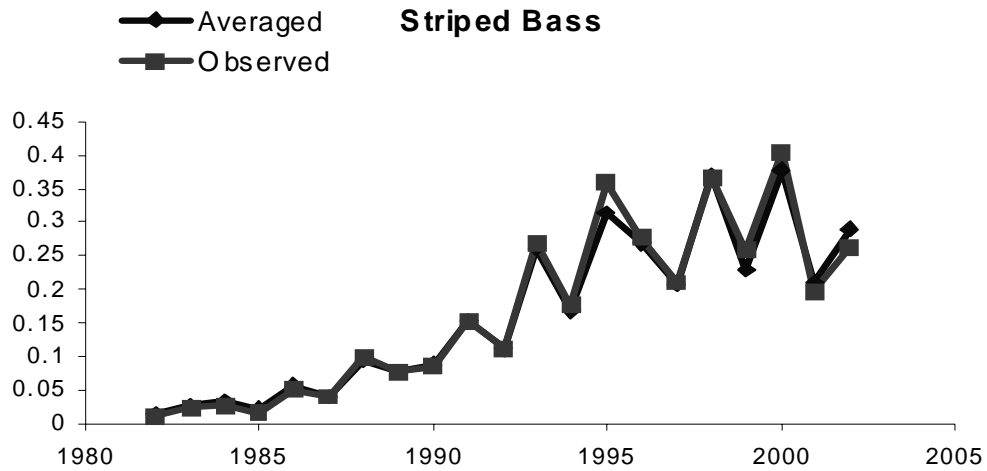


Figure D1.72. Predation mortality (M2) of menhaden by weakfish calculated based on variable (observed) weight-at-age and based on constant weight-at-age

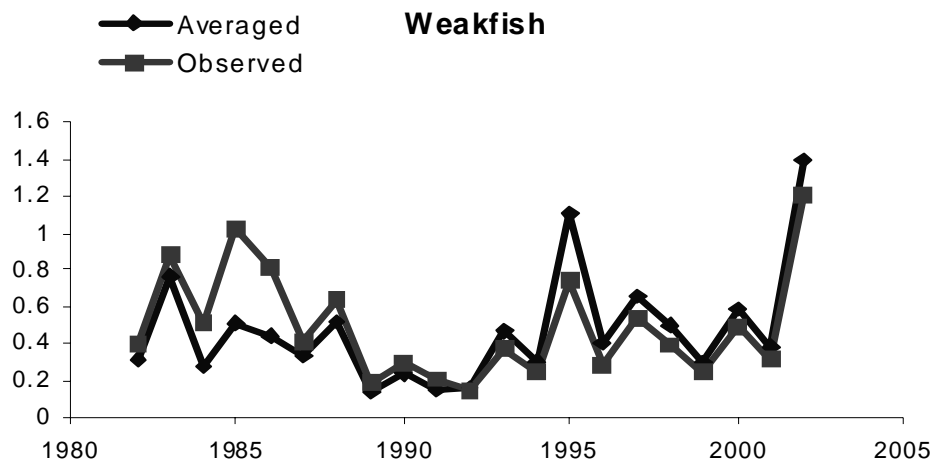
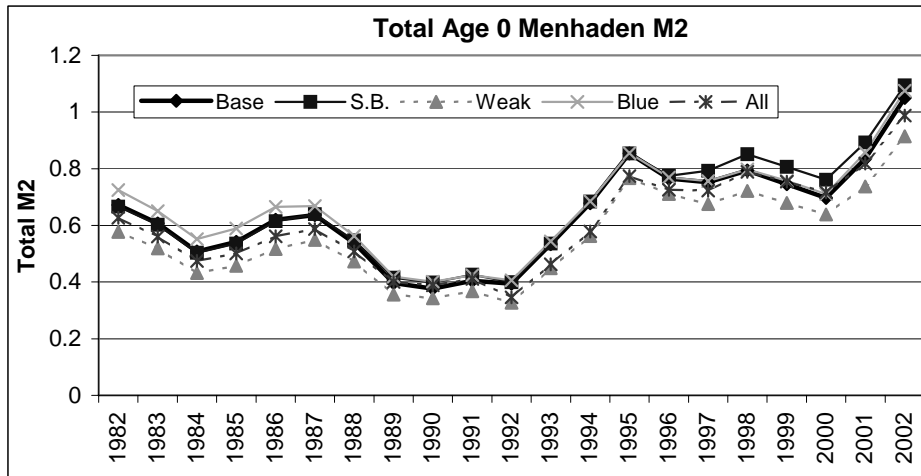
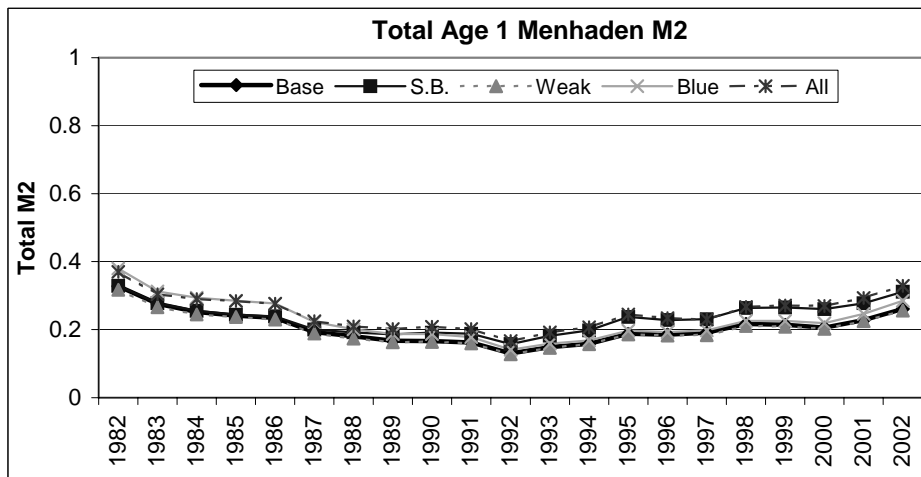


Figure D1.73a - c. Annual total menhaden predation mortality for the different predator runs. See Table D1.14 for explanation of model runs.

a.)



b.)



c.)

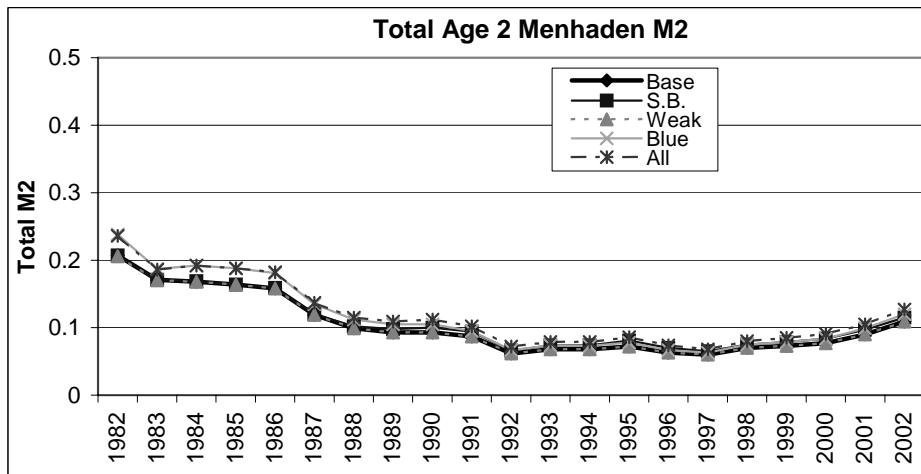
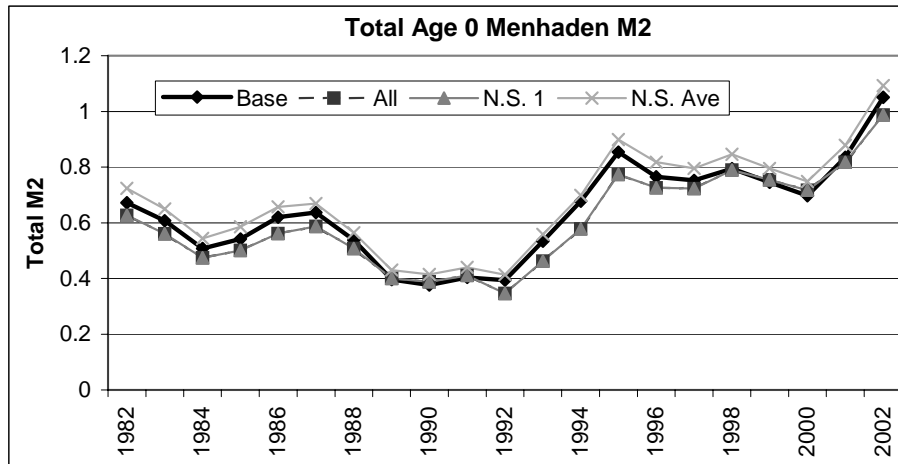
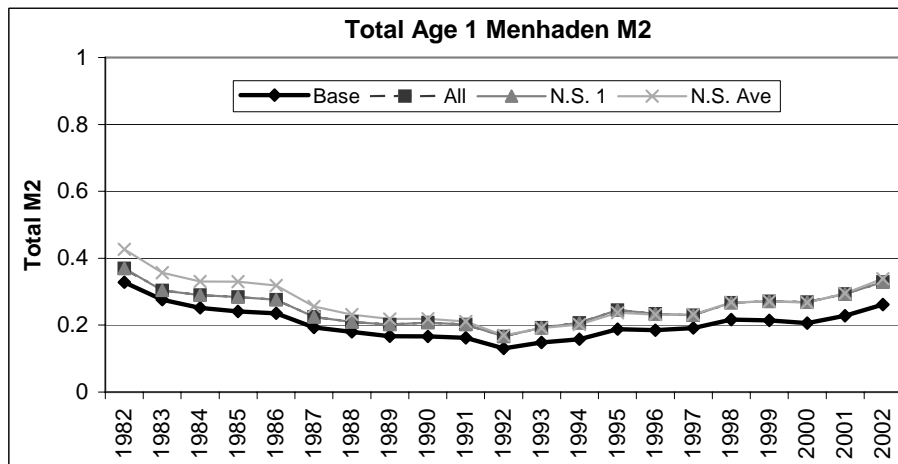


Figure D1.74a - c. Annual total Menhaden predation mortality for the different seasonal runs. See Table D1.14 for explanation of model runs.

a.)



b.)



c.)

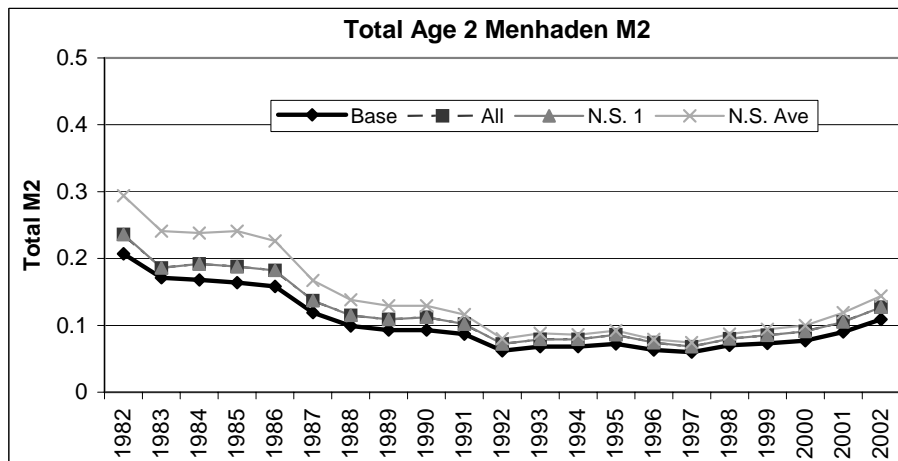
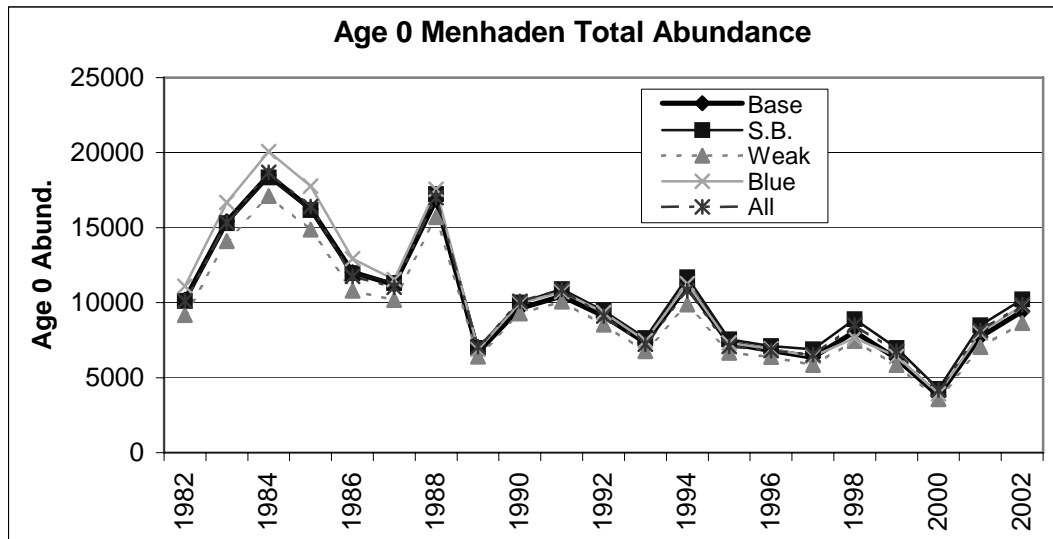


Figure D1.75a - b. Total menhaden abundance (millions of fish) by age for the different Predator runs.

a.)



b.)

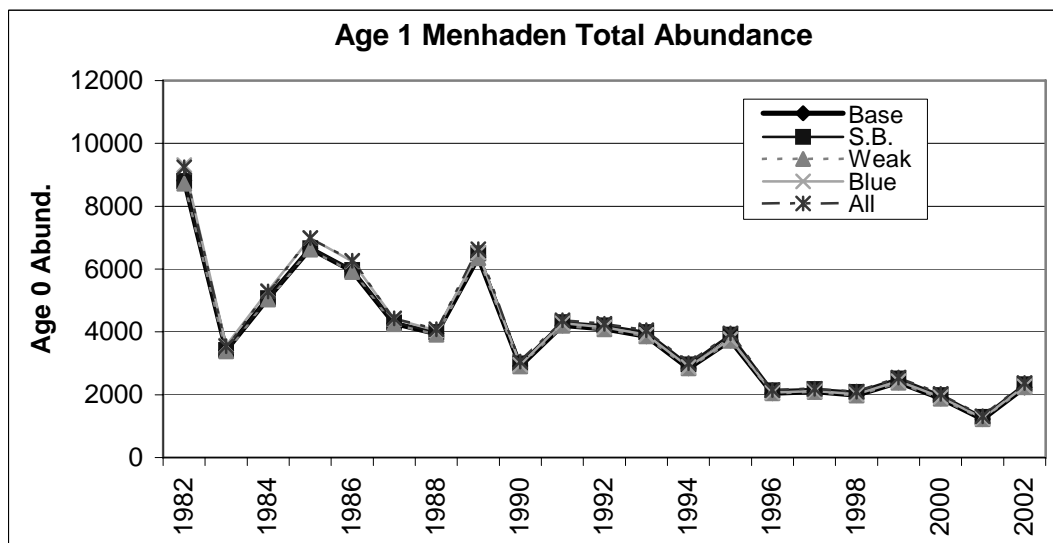
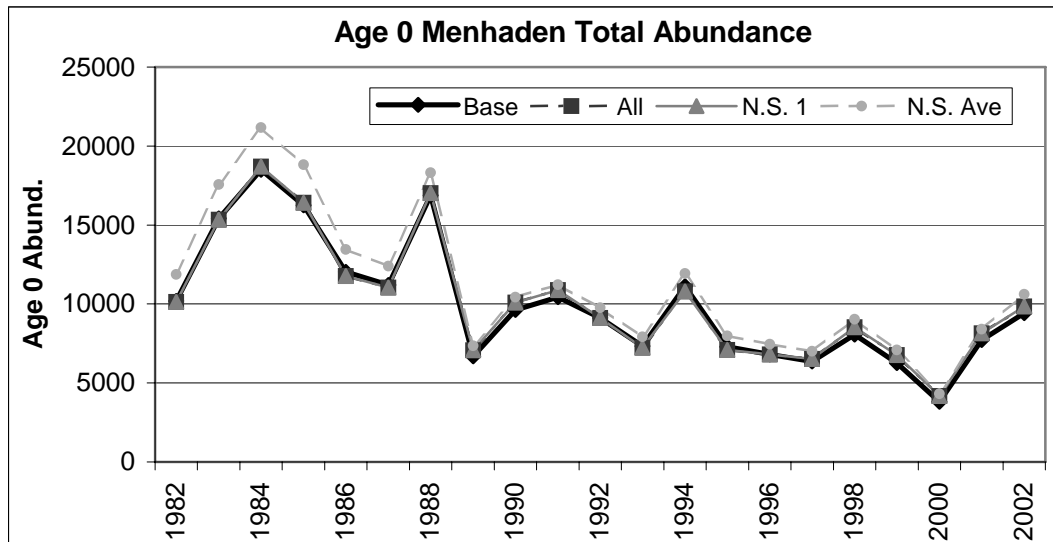


Figure D1.76. Total menhaden abundance (millions of fish) by age for the different Seasonal runs

a.)



b.)

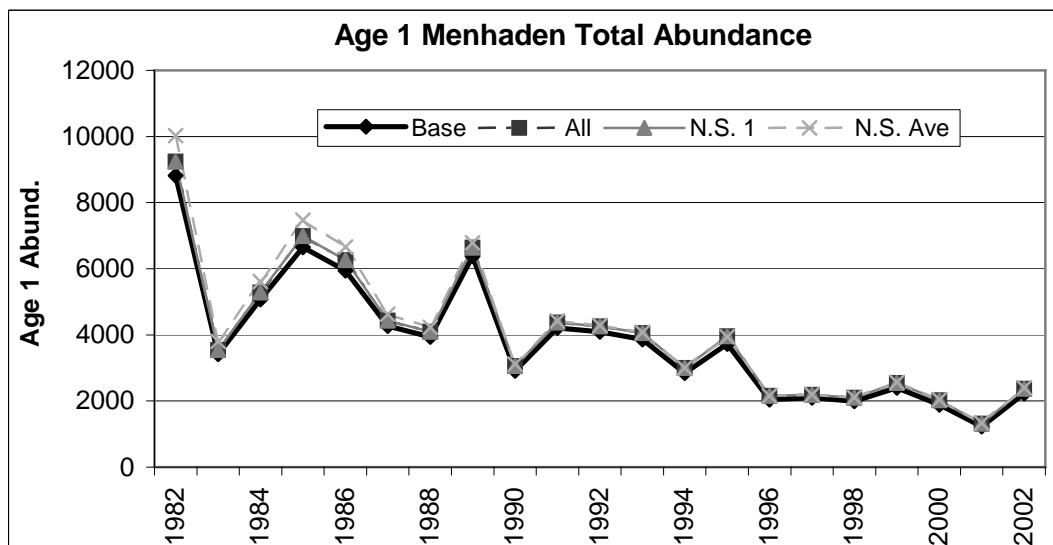
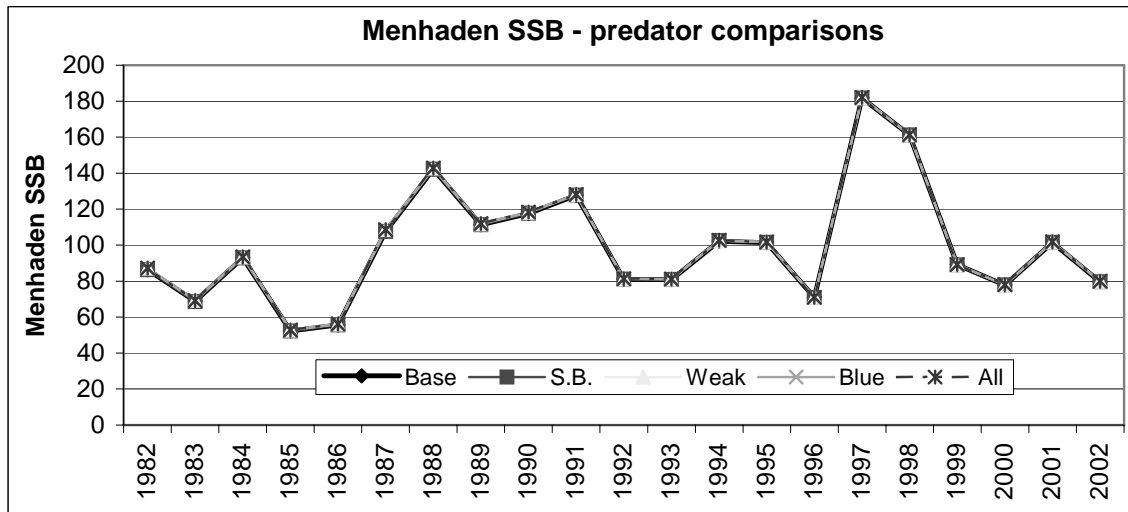


Figure D1.77. Annual menhaden spawning stock biomass (SSB in 000 mt) a.) Predator runs b.) Seasonal runs.

a.)



b.)

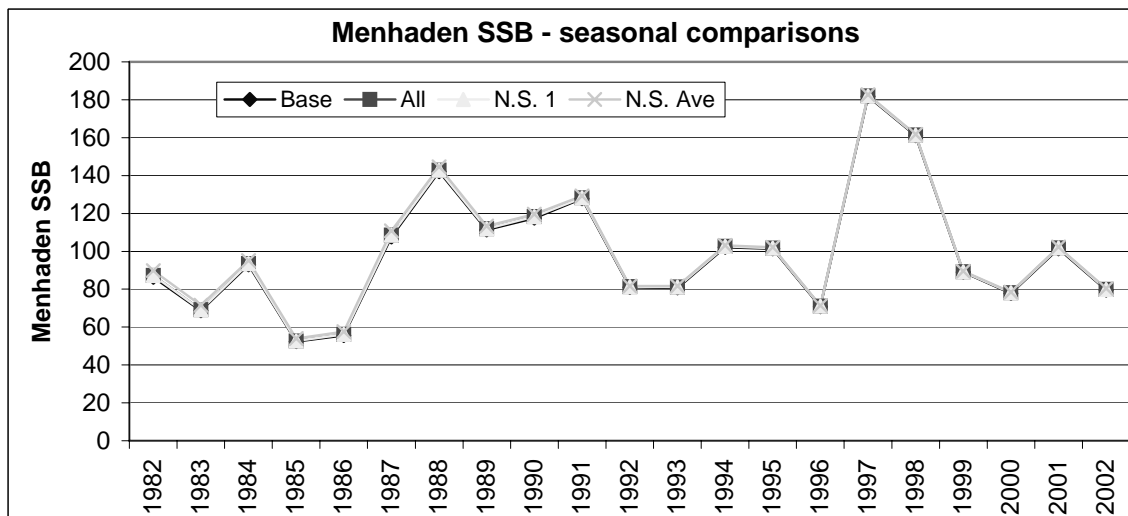
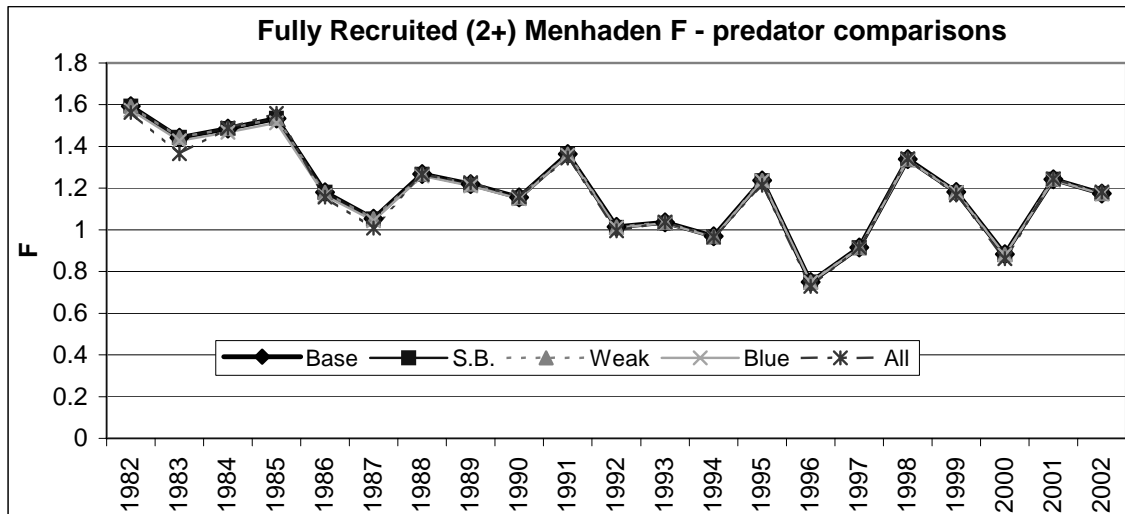


Figure D1.78a - b. Annual menhaden fully recruited (2+) fishing mortality (F) a.) Predator runs b.) Seasonal.

a.)



b.)

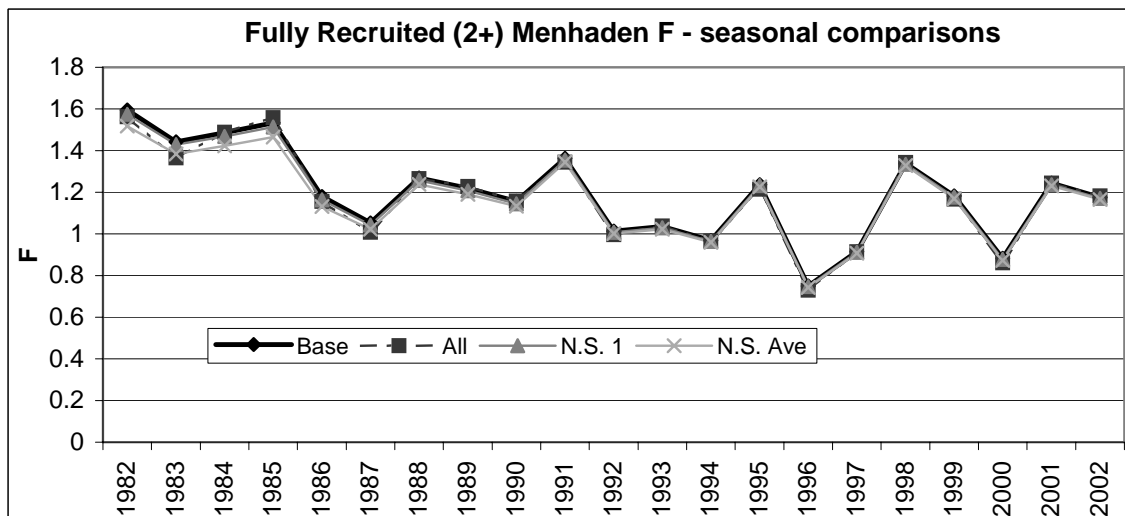


Figure D1.79a - f. The relative change in the proportion of a particular prey item in the diet of each predator by age ((sensitivity run prop./base run prop.) - 1)). Figures a – c compare the Weak run to the Base and figures d - f compare the All predator run to the Base.

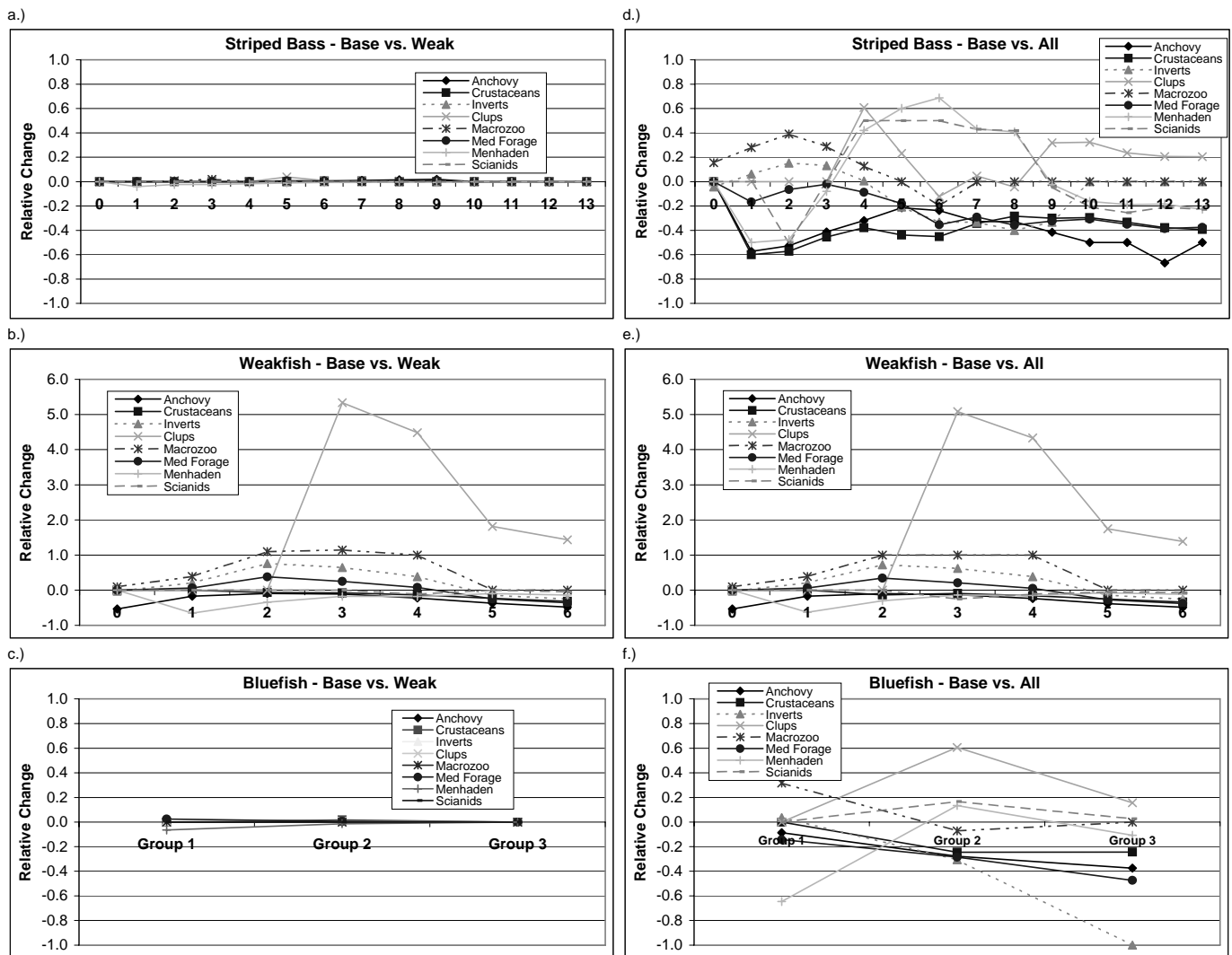


Figure D1.80a - c. Average proportion of prey, for a few key species, in diet by predator and age. Figures compare Predator runs for the Base, the model run where that specific predator spatial overlap was = to 1, and where all predators overlap was equal to 1 - a.) striped bass b.) weakfish c.) bluefish.

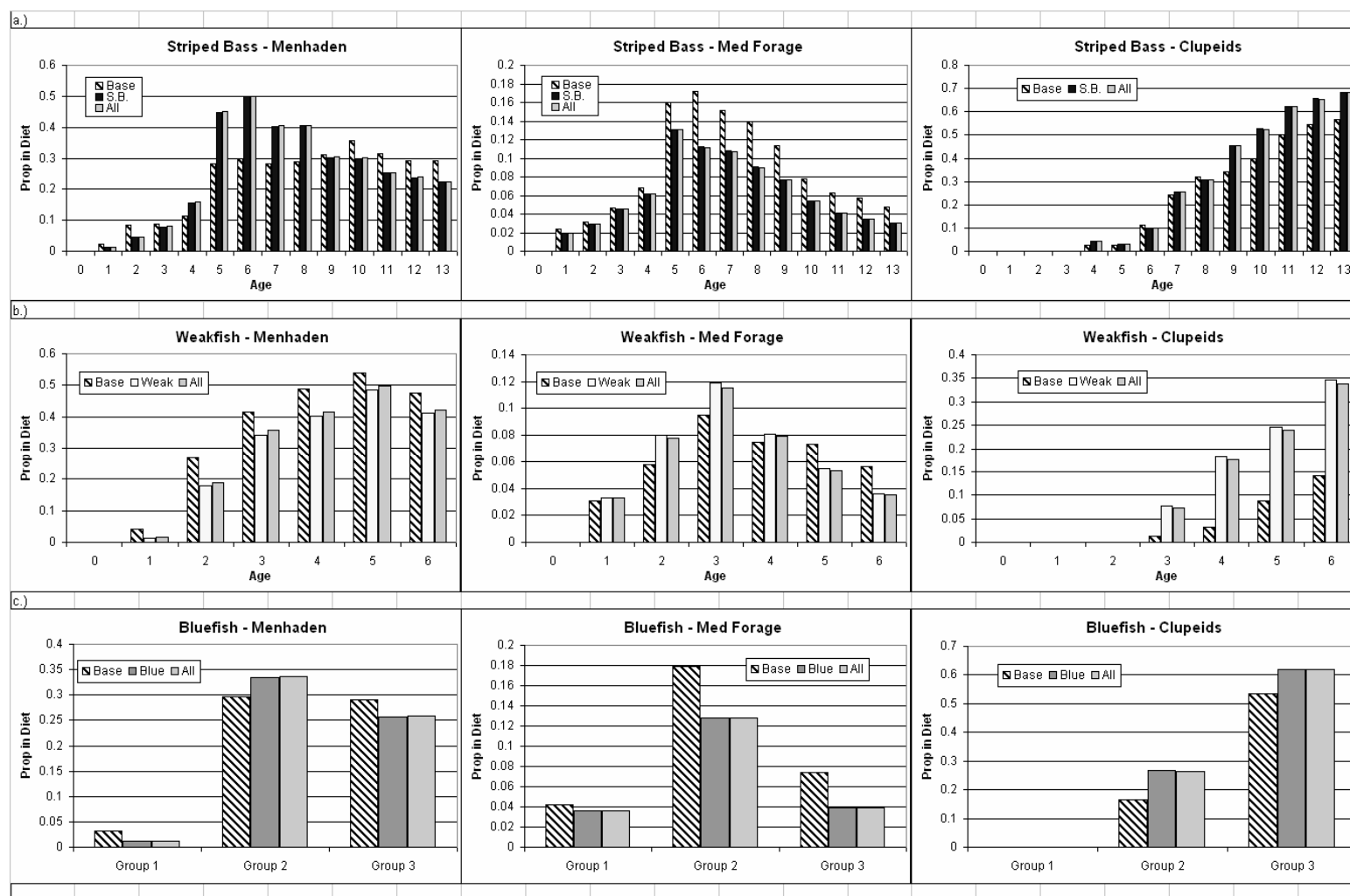


Figure D1.81a - c. Total consumption (biomass, 1000 mt) by year and by each predator for a few key prey species for each Predator run - a.) striped bass b.) weakfish c.) bluefish.

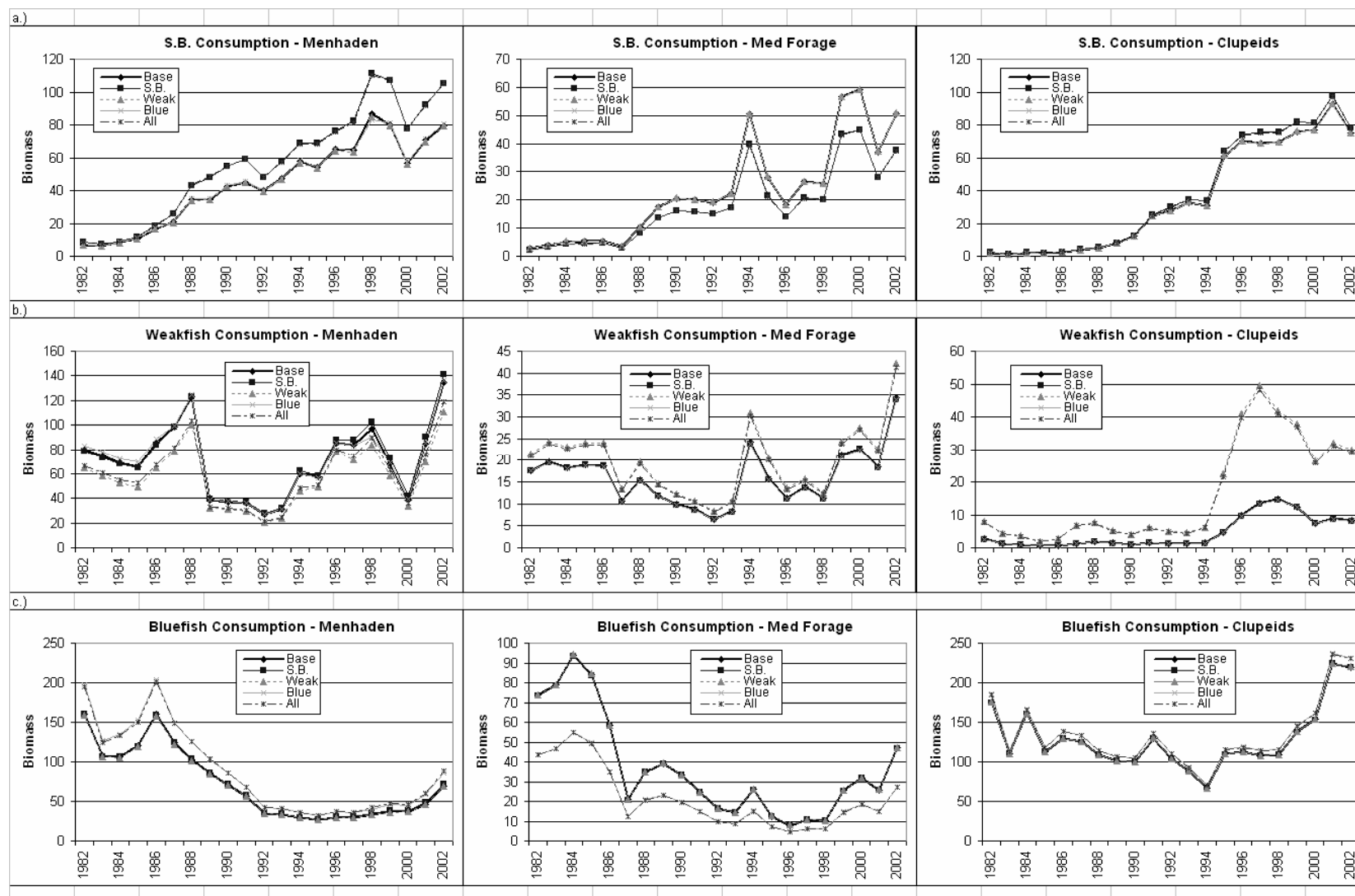
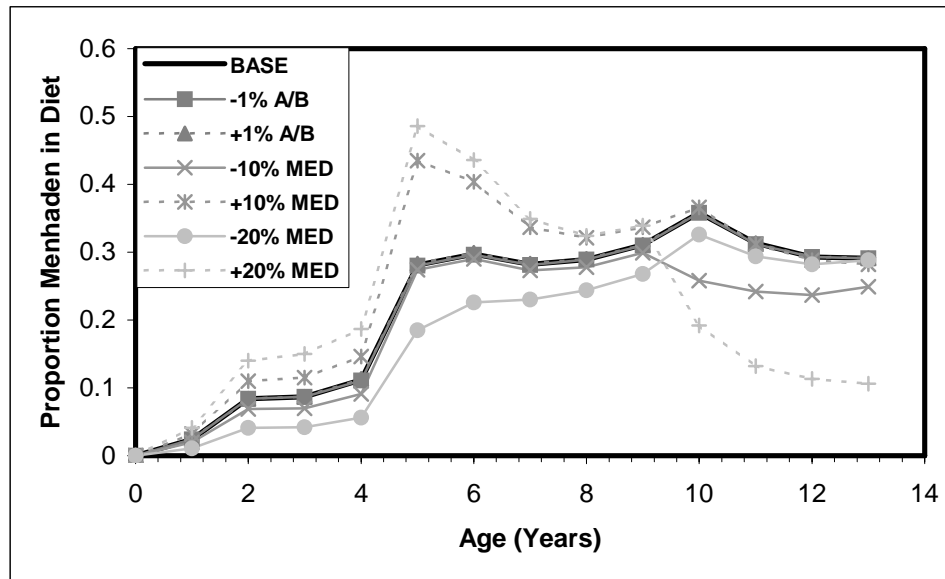


Figure D1.82. Average proportion of menhaden in striped bass (a), weakfish (b) and bluefish (c) diets by year. Results are shown for the base run, two scenarios in which the size selectivity curve parameters α and β were changed by $\pm 1\%$, and four scenarios in which the median size of prey selected for each predator was shifted by $\pm 10\%$ and $\pm 20\%$.

a)



b)

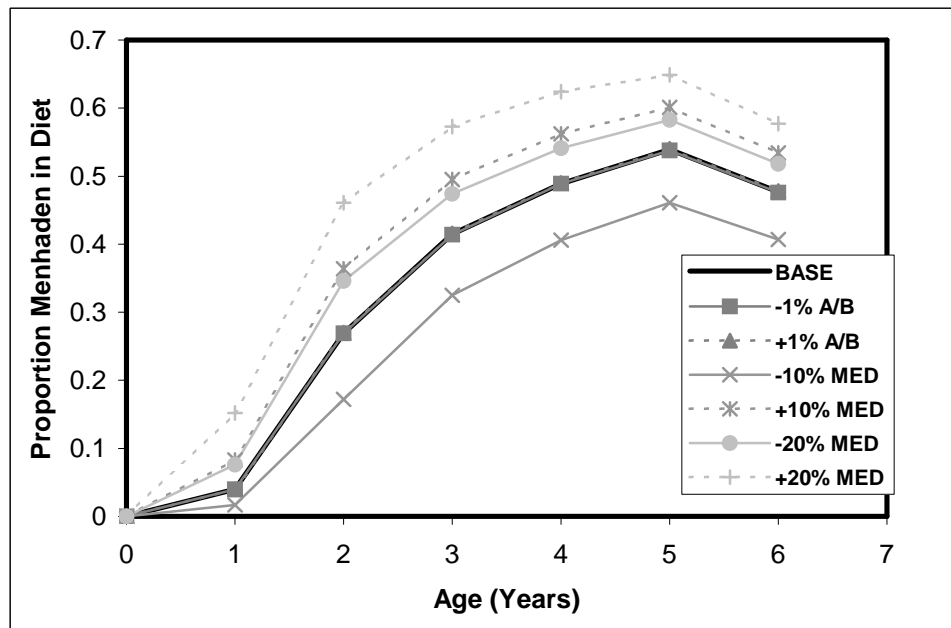


Figure D1.82 (Cont'd). Average proportion of menhaden in striped bass (a), weakfish (b) and bluefish (c) diets by year. Results are shown for the base run, two scenarios in which the size selectivity curve parameters α and β were changed by $\pm 1\%$, and four scenarios in which the median size of prey selected for each predator was shifted by $\pm 10\%$ and $\pm 20\%$.

c)

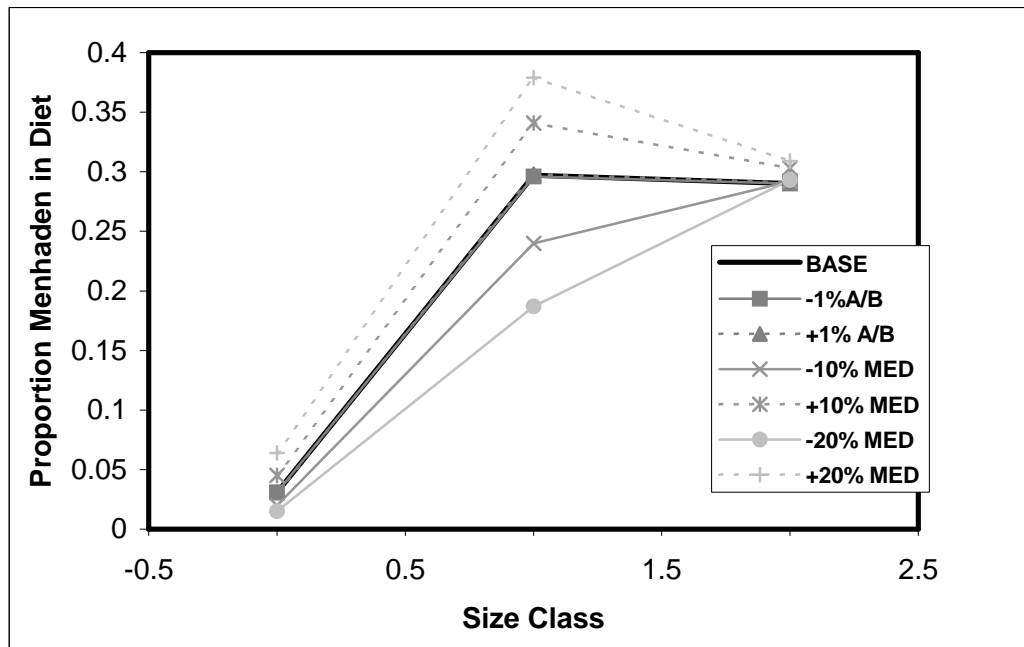
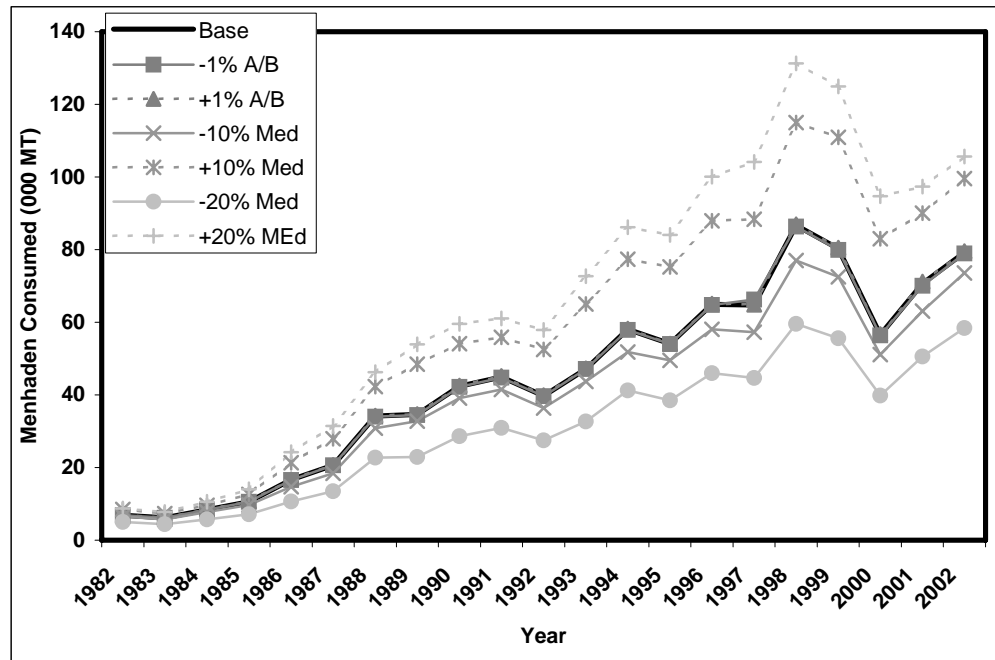


Figure D1.83. Total menhaden consumed in thousands of metric tons by striped bass (a), weakfish (b), and bluefish (c) by year. Results are shown for the base run, two scenarios in which the size selectivity curve parameters α and β were changed by $\pm 1\%$, and four scenarios in which the median size of prey selected for each predator was shifted by $\pm 10\%$ and $\pm 20\%$.

a)



b)

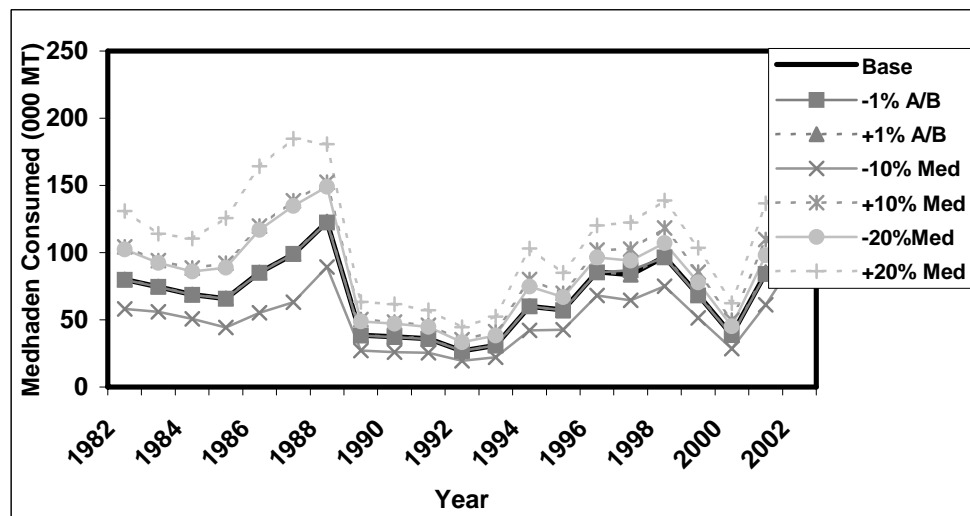


Figure D1.83 (Cont'd). Total menhaden consumed in thousands of metric tons by striped bass (a), weakfish (b), and bluefish (c) by year. Results are shown for the base run, two scenarios in which the size selectivity curve parameters α and β were changed by $\pm 1\%$, and four scenarios in which the median size of prey selected for each predator was shifted by $\pm 10\%$ and $\pm 20\%$.

c)

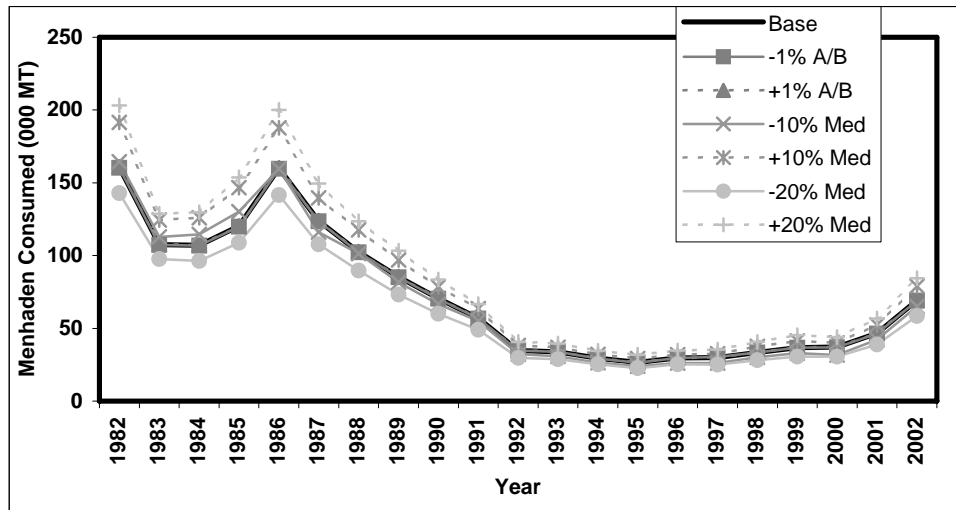
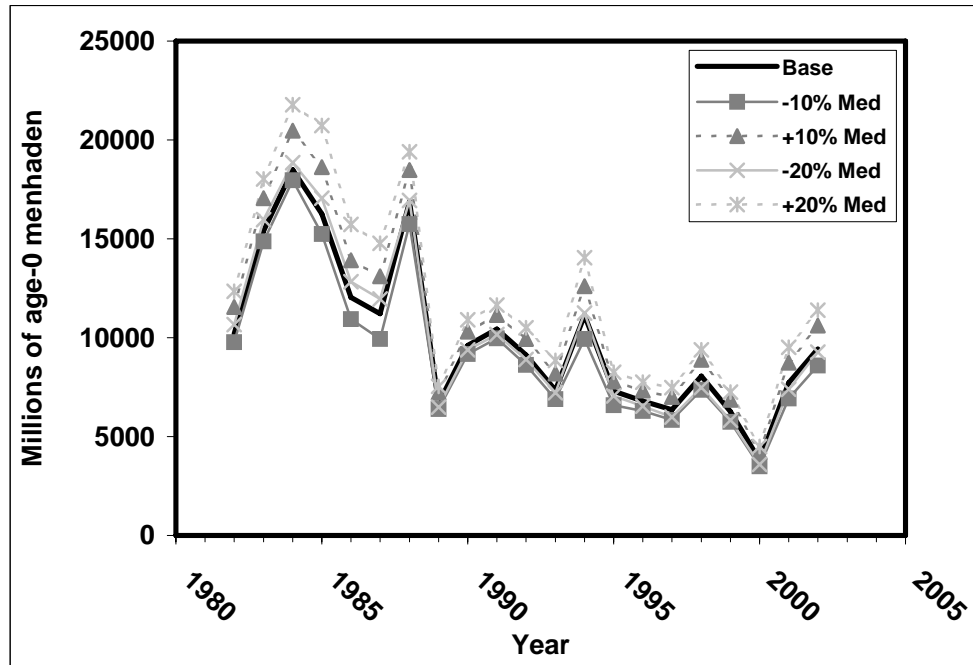


Figure D1.84 Age-0 (a), age-1 (b), and total abundance (c) of menhaden from the base run MSVPA and for four scenarios in which the median size of prey selected for each predator was shifted by $\pm 10\%$ and $\pm 20\%$.

a)



b)

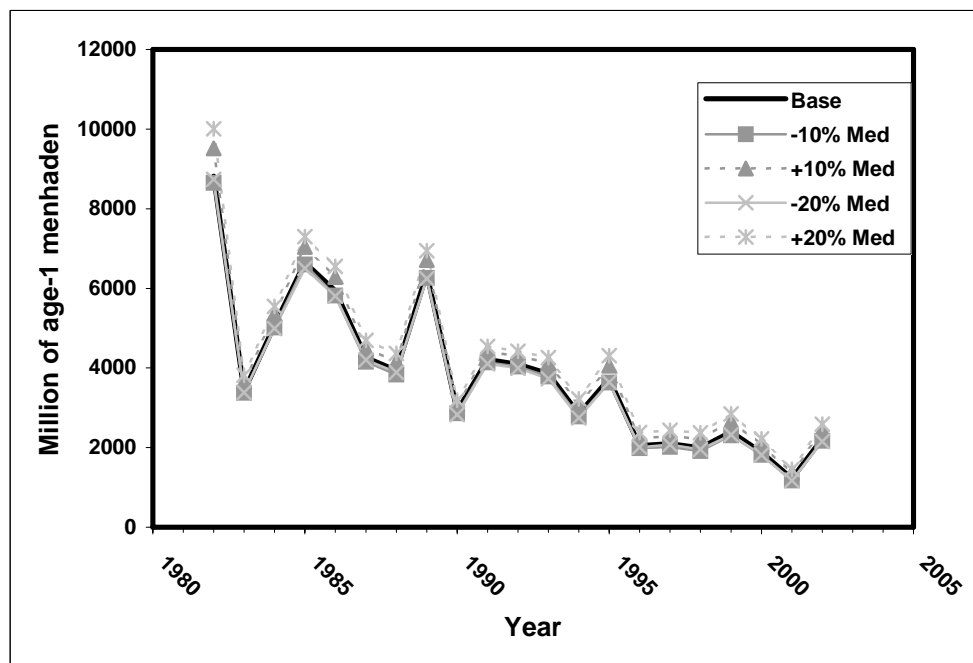


Figure D1.84 (Cont'd). Age-0 (a), age-1 (b), and total abundance (c) of menhaden from the base run MSVPA and for four scenarios in which the median size of prey selected for each predator was shifted by $\pm 10\%$ and $\pm 20\%$.

c)

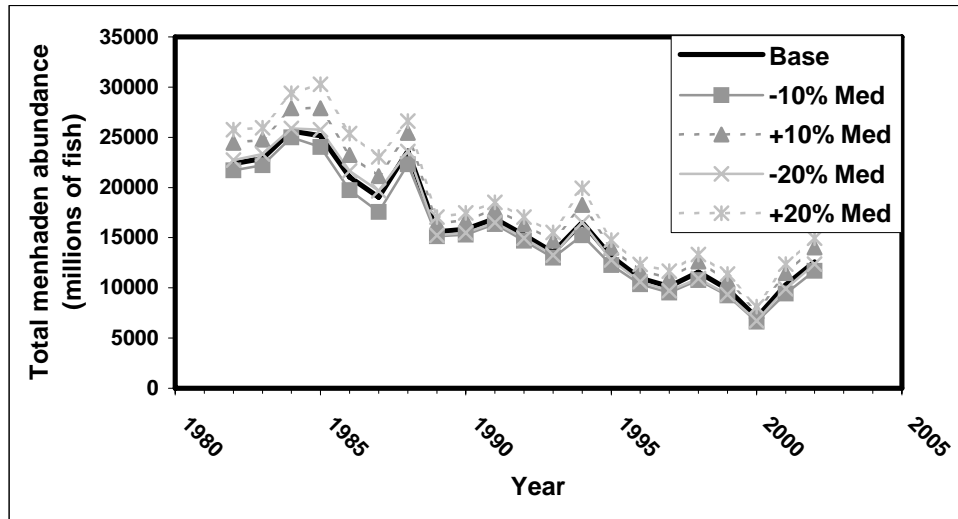
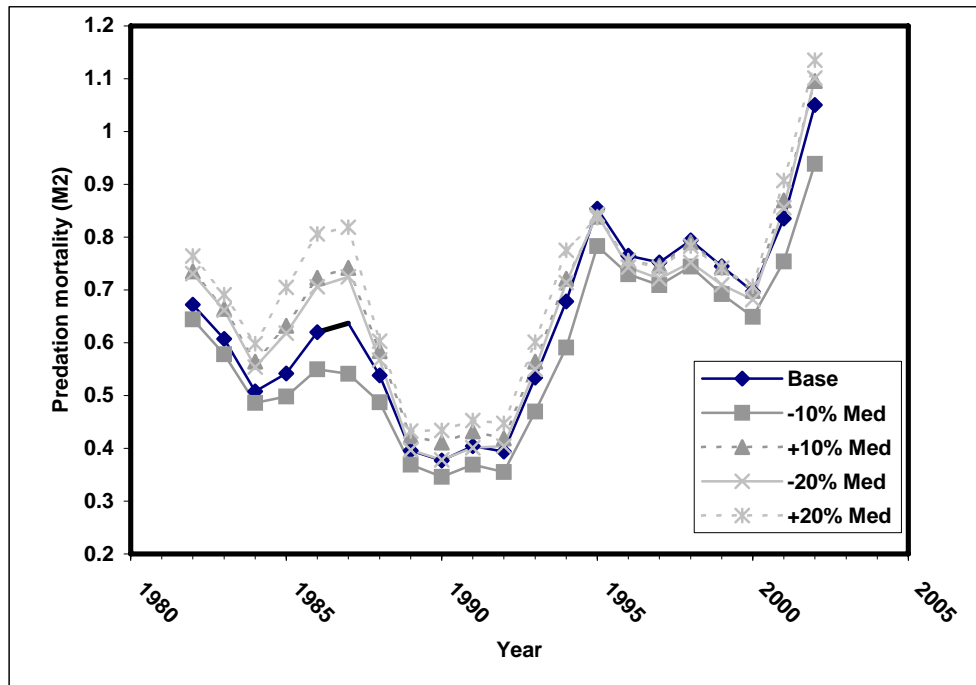


Figure D1.85. Predation mortality rates (M2) on age-0 (a) and age-1 (b) menhaden for each year. M2 values for the base run configuration are plotted against M2 values from scenarios in which the median size of prey selected for each predator was shifted by $\pm 10\%$ and $\pm 20\%$.

a)



b)

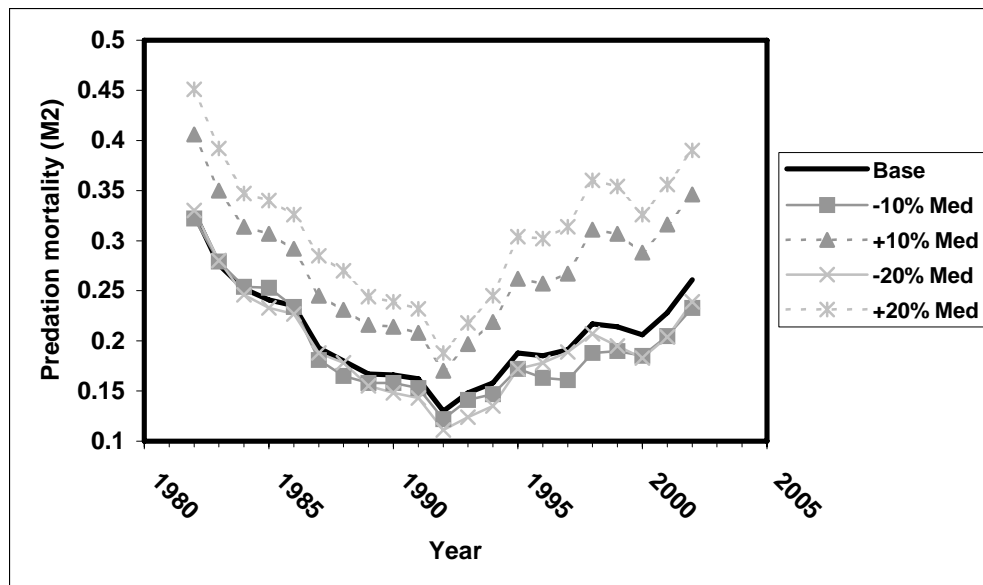
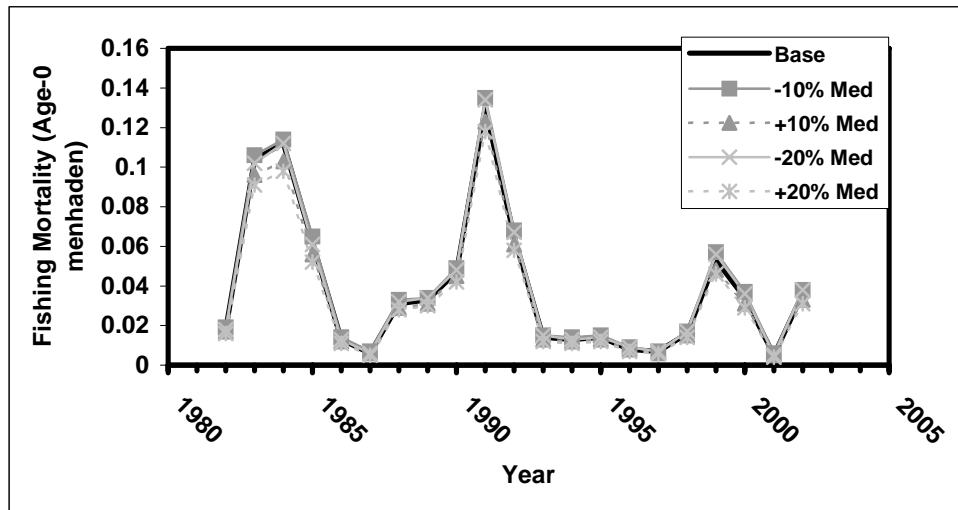


Figure D1.86. Fishing mortality estimates on age-0 (a), age-3 (b) and age-6+ (c) menhaden in the MSVPA-X. Results are shown for the base run configuration and for scenarios in which the median size of prey selected for each predator was shifted by $\pm 10\%$ and $\pm 20\%$.

a)



b)

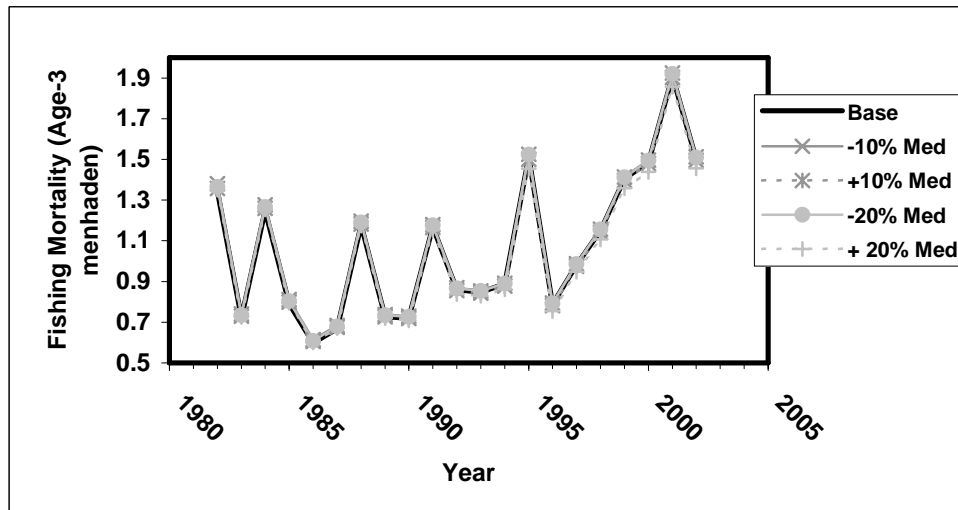


Figure D1.86 (Cont'd). Fishing mortality estimates on age-0 (a), age-3 (b) and age-6+ (c) menhaden in the MSVPA-X. Results are shown for the base run configuration and for scenarios in which the median size of prey selected for each predator was shifted by $\pm 10\%$ and $\pm 20\%$.

c)

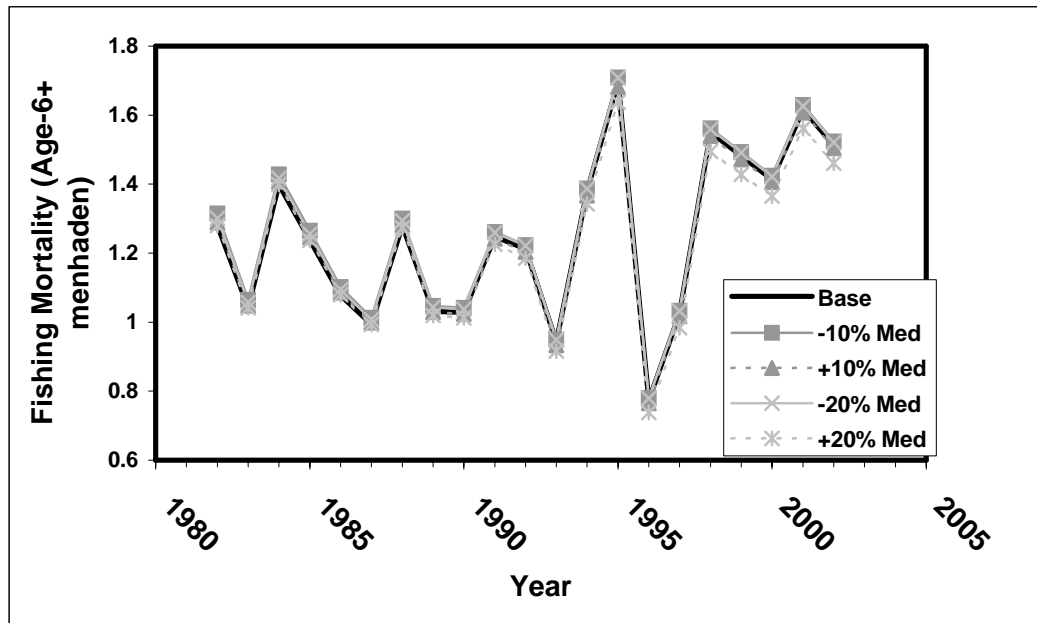
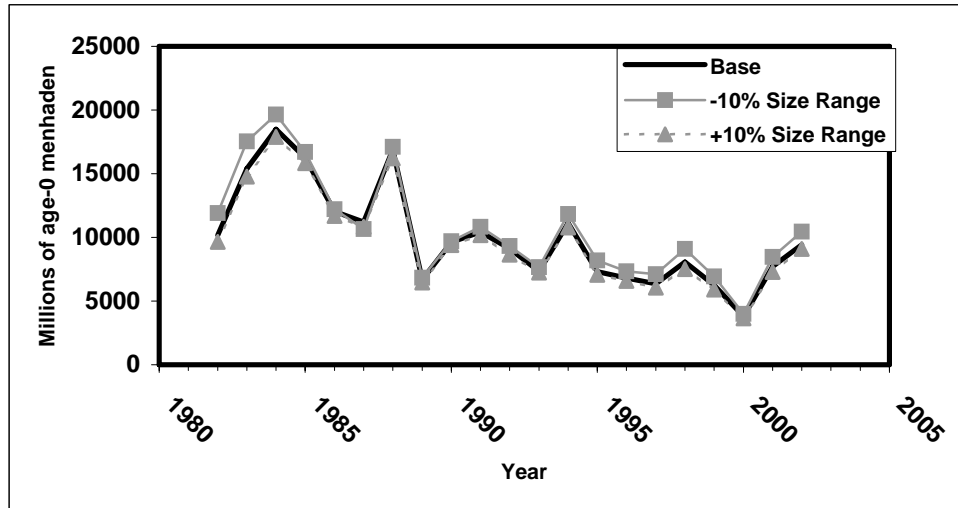


Figure D1.87. Age-0 (a), age-1 (b) and total abundance (c) of menhaden from the base run MSVPA for two scenarios in which the range of prey size selectivity for each predator was increased or decrease by $\pm 10\%$.

a)



b)

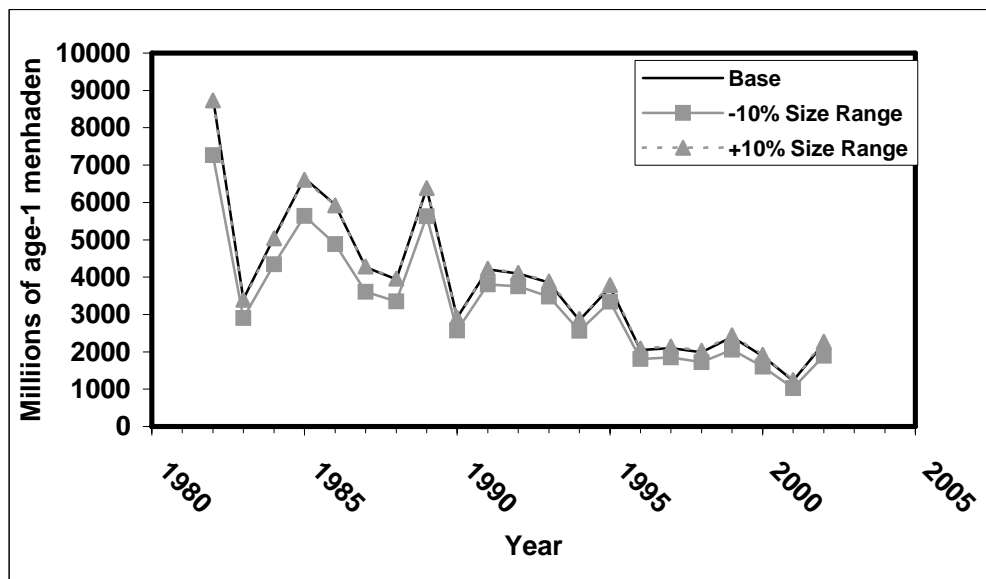


Figure D1.87 (cont'd). Age-0 (a), age-1 (b) and total abundance (c) of menhaden from the base run MSVPA for two scenarios in which the range of prey size selectivity for each predator was increased or decrease by $\pm 10\%$.

c)

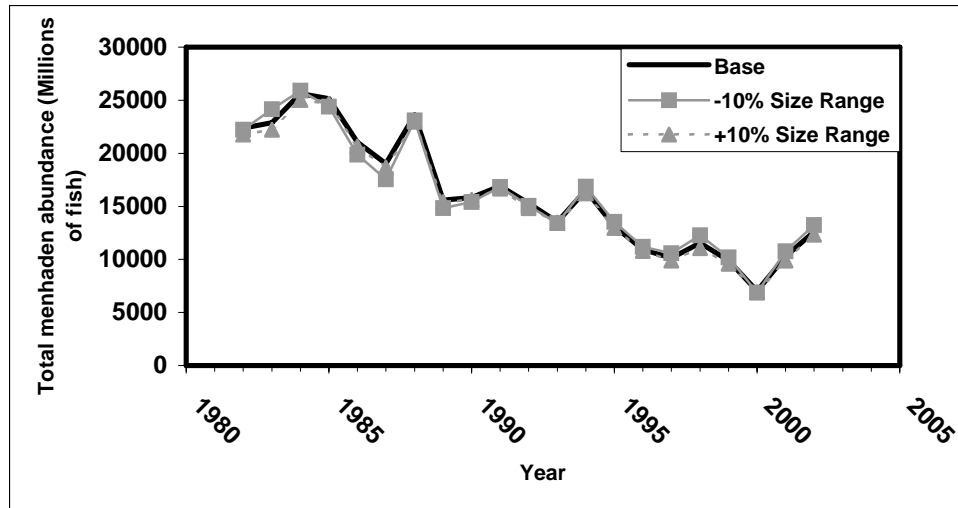


Figure D1.88. Spawning stock biomass (SSB in 000 mt) of menhaden from the base run MSVPA and for two scenarios in which the range of prey size selectivity for each predator was increased or decrease by $\pm 10\%$.

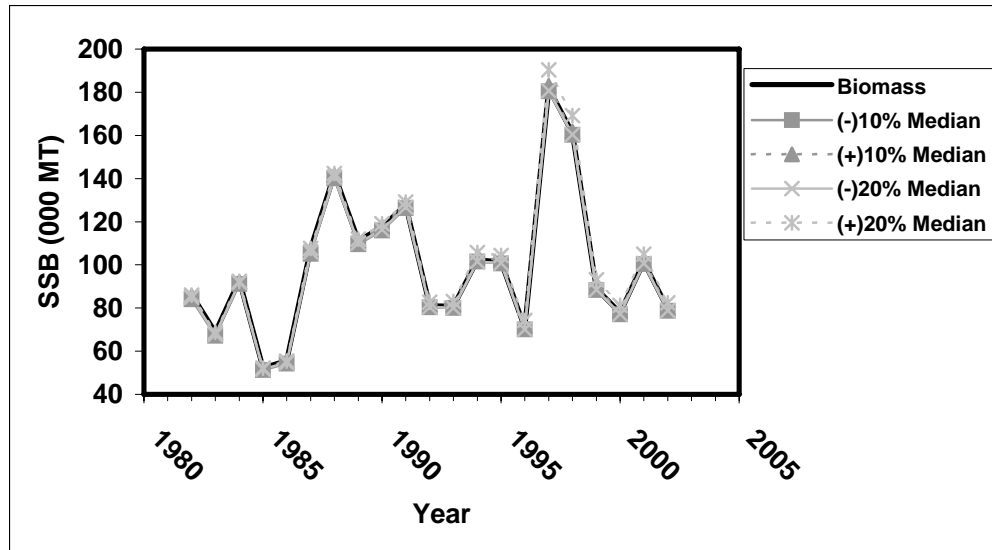
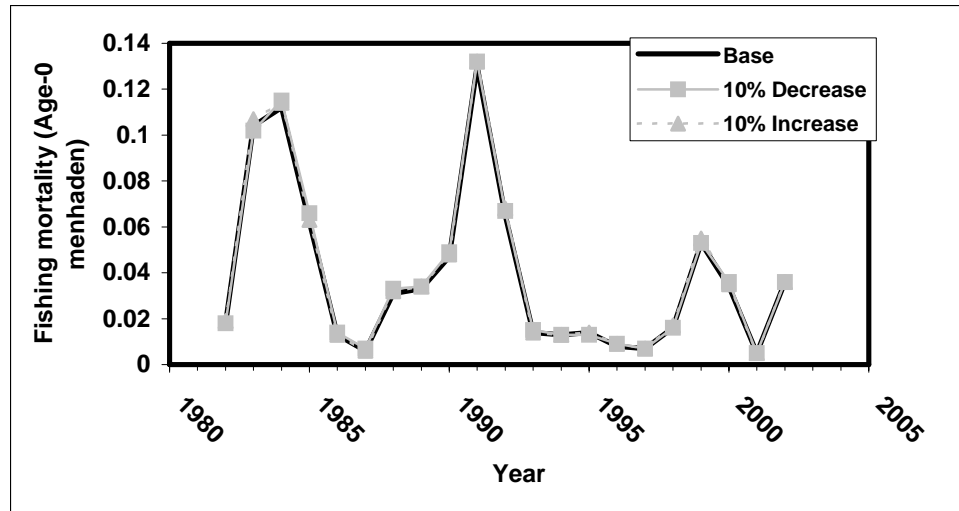


Figure D1.89. Fishing mortality (F) estimates for age-0 (a), age-3 (b), age-6+ (c) and average recruited F (age-2+) menhaden from the base run MSVPA and for two scenarios in which the range of prey size selectivity for each predator was increased or decrease by $\pm 10\%$.

a)



b)

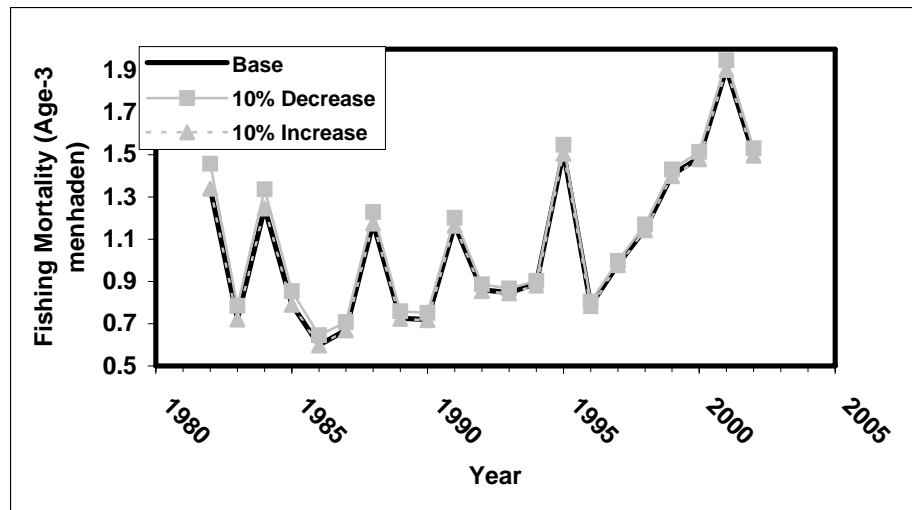
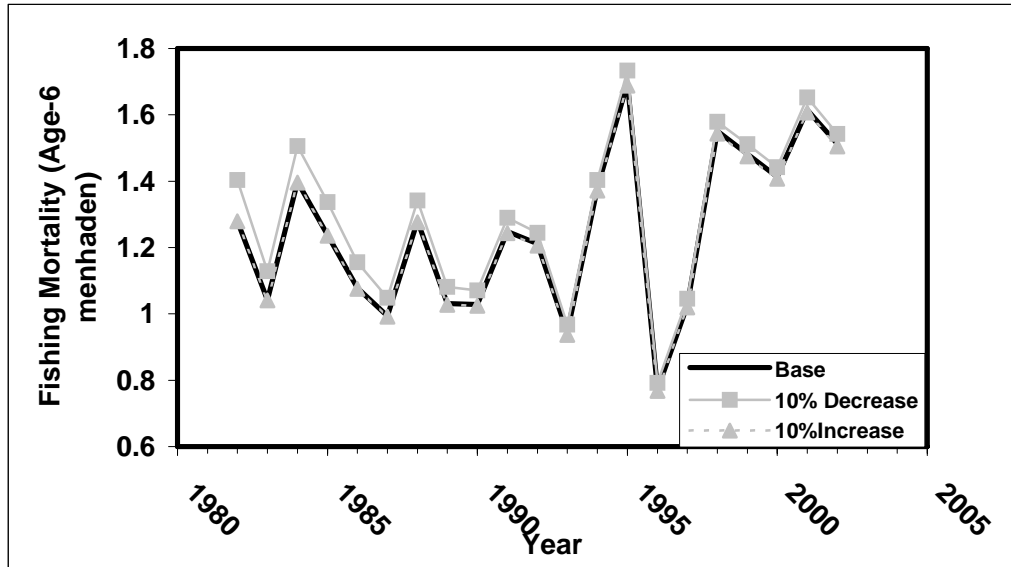


Figure D1.89 (cont'd). Fishing mortality (F) estimates for age-0 (a), age-3 (b), age-6+ (c) and average recruited F (age-2+) menhaden from the base MSVPA and for two scenarios in which the range of prey size selectivity for each predator was increased or decrease by $\pm 10\%$.

c)



d)

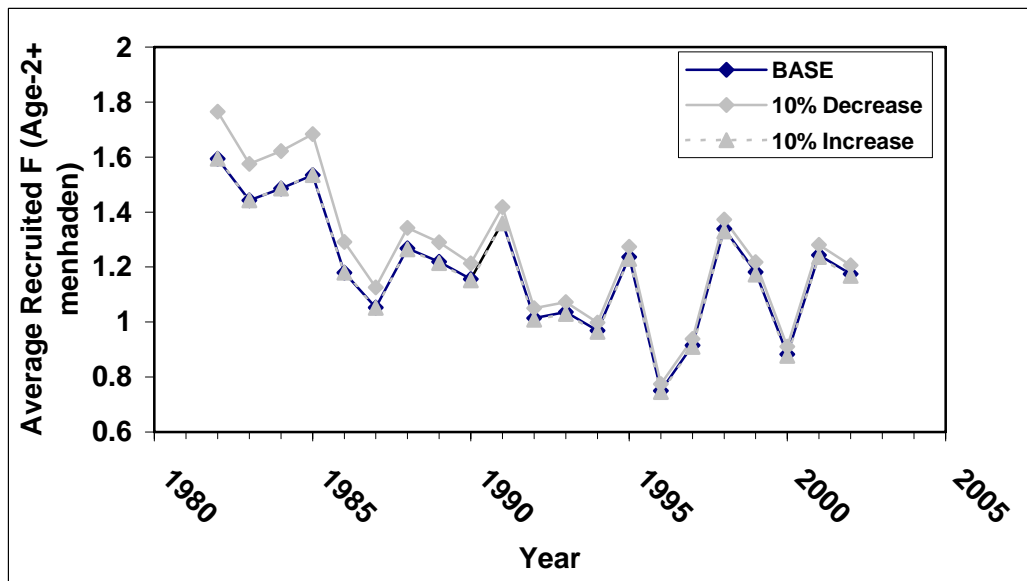
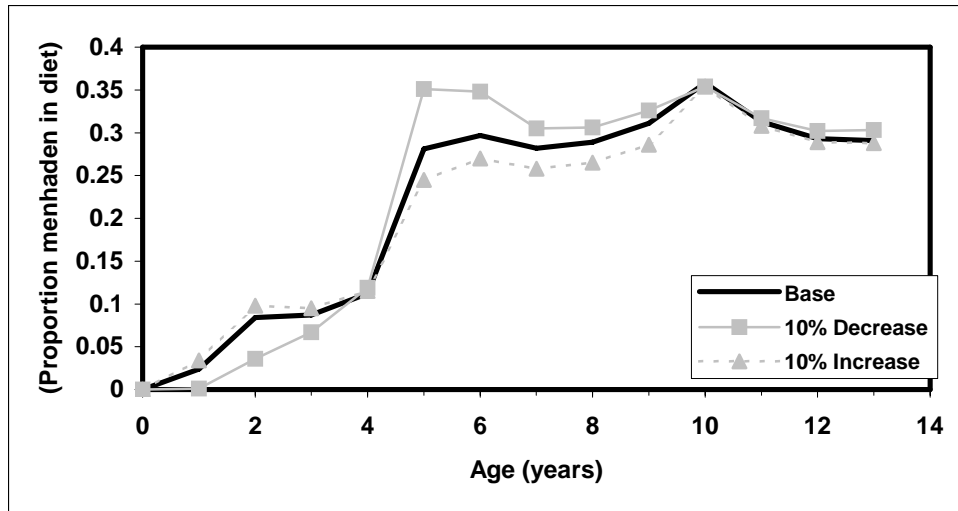


Figure D1.90. Proportion of menhaden in the diet of striped bass (a), weakfish (b), and bluefish (c) by age for the base run MSVPA-X configuration and for two scenarios in which the range of prey size selectivity for each predator was increased or decrease by $\pm 10\%$.

a)



b)

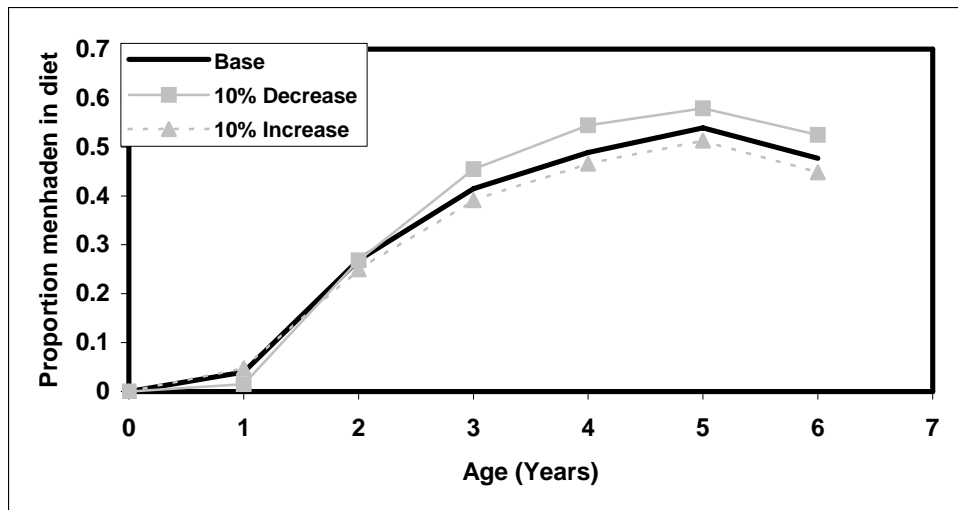


Figure D1.90 (cont'd). Proportion of menhaden in the diet of striped bass (a), weakfish (b), and bluefish (c) by age for the base run MSVPA-X configuration and for two scenarios in which the range of prey size selectivity for each predator was increased or decrease by $\pm 10\%$.

c)

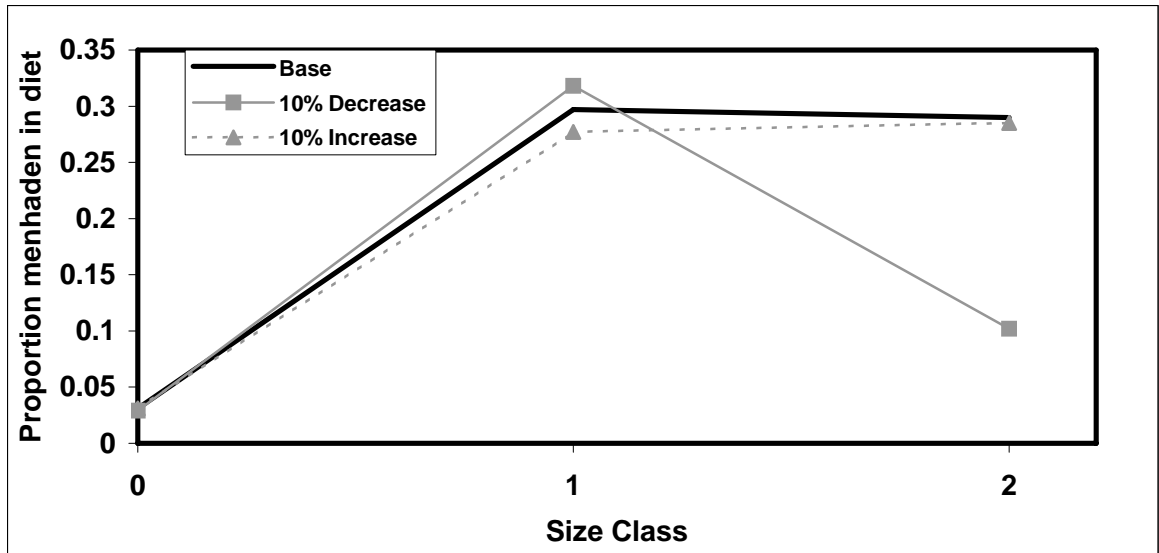
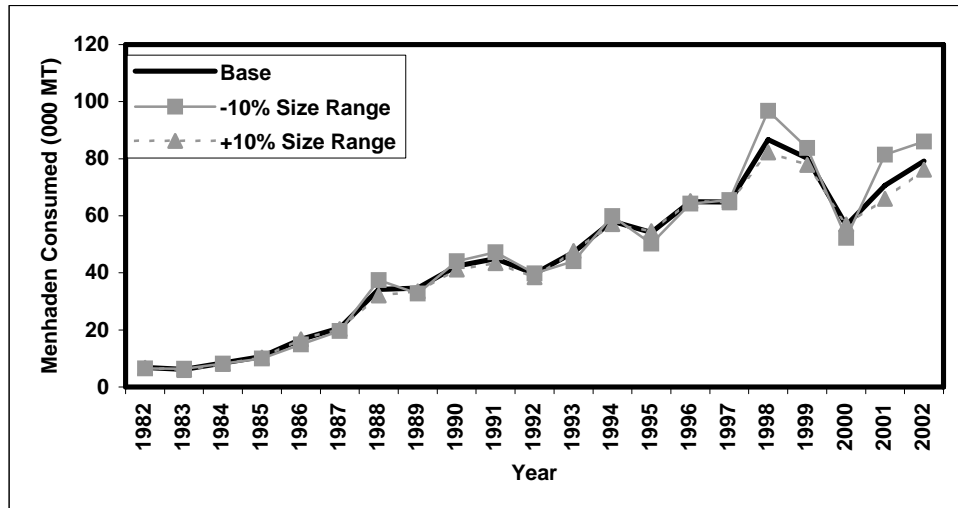


Figure D1.91. Total menhaden consumed by striped bass (a), weakfish (b), and bluefish (c) by year for the base run MSVPA-X configuration and for two scenarios in which the range of prey size selectivity for each predator was increased or decrease by $\pm 10\%$.

a)



b)

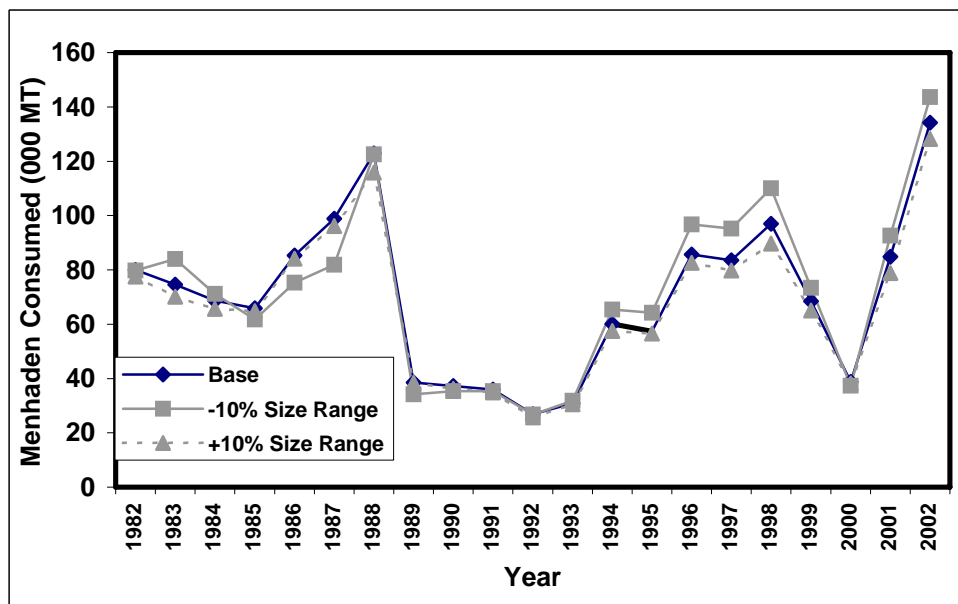


Figure D1.91 (cont'd). Total menhaden consumed by striped bass (a), weakfish (b), and bluefish (c) by year for the base run MSVPA-X configuration and for two scenarios in which the range of prey size selectivity for each predator was increased or decrease by $\pm 10\%$.

c)

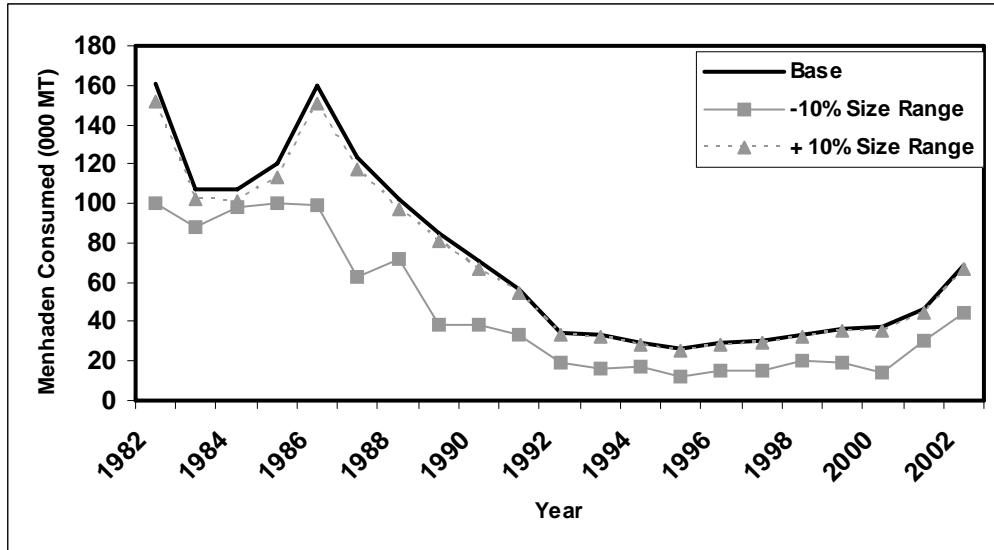


Figure D1.92. Comparison of observed (base run) and forecasted (using observed catch or observed F) menhaden population parameters dynamics for 1996-2002. The units for total biomass and spawning stock biomass are in 000 mt and total abundance is in millions of fish.

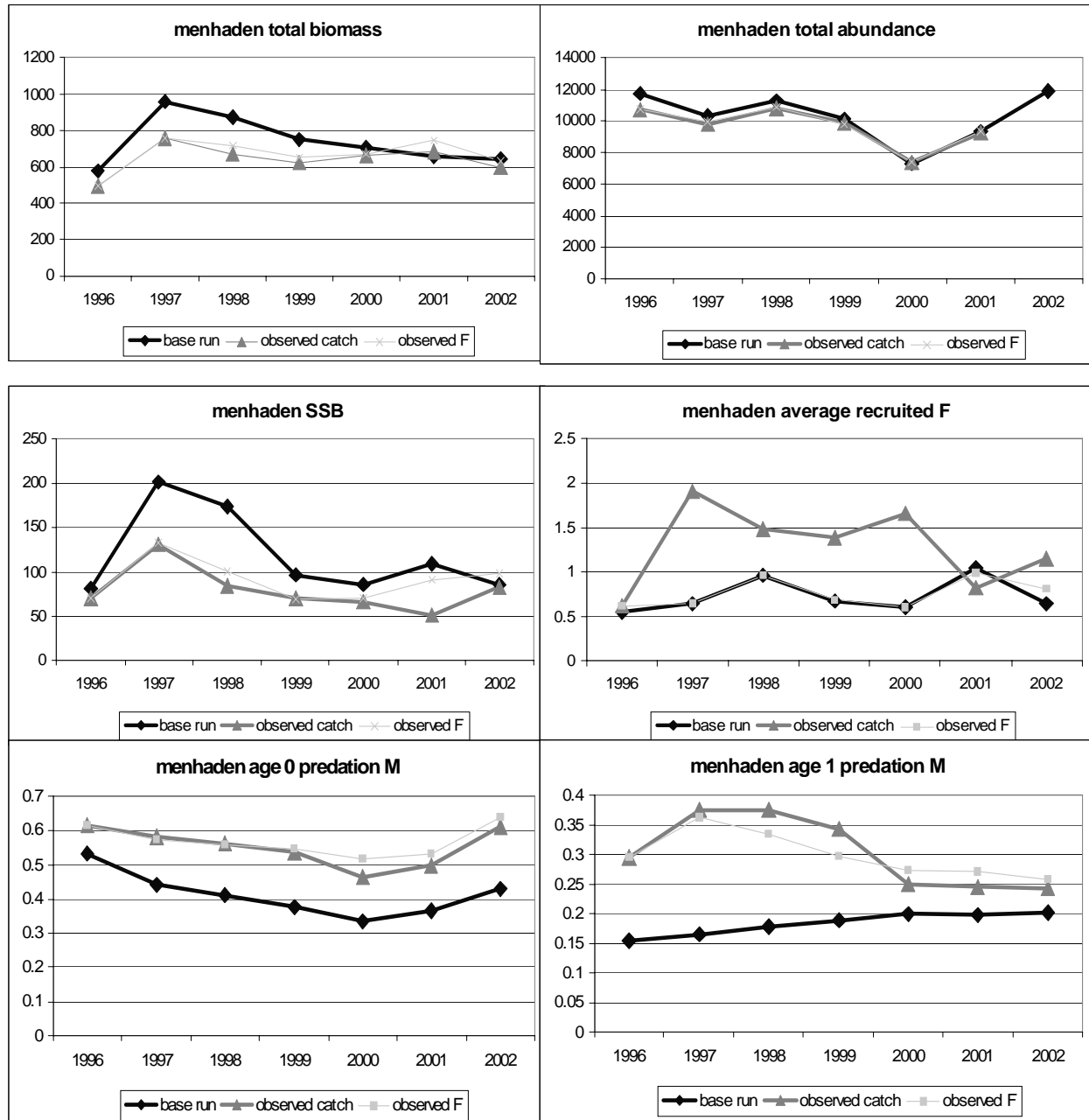
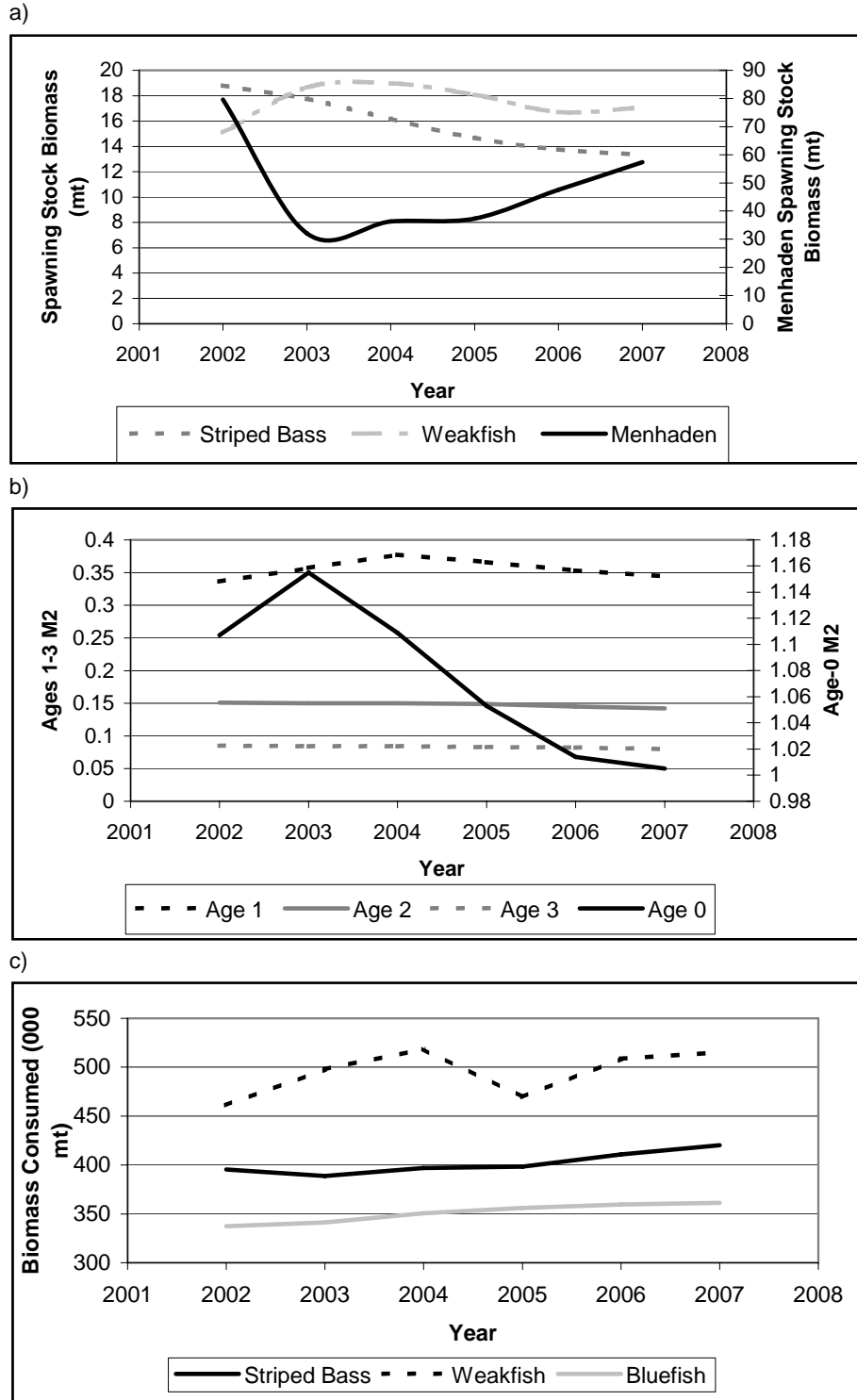


Figure D1.93(a-c). Results of the forward projection for: a) spawning stock biomass of menhaden, striped bass and weakfish; b) predation mortality on age-0 through age-3 menhaden; and c) the amount of menhaden consumed by striped bass, weakfish and bluefish.



APPENDIX D2: ASMFC SINGLE-SPECIES RESEARCH RECOMMENDATIONS

ATLANTIC MENHADEN

ASMFC Special Report #81: Prioritized Research Needs in Support of Interjurisdictional Fisheries Management June 2004 (ASMFC, 2004c)

Prioritized Research Needs

1. Evaluate effects of selected environmental factors on growth, survival and abundance of juvenile and adult menhaden, particularly in Chesapeake Bay and other coastal nursery areas.
 - Develop and test methods for estimating size of recruiting year-classes of juveniles using fishery-independent survey techniques.
 - Determine how loss/degradation of critical estuarine and nearshore habitat affects growth, survival and abundance of juvenile and adult menhaden abundance.
 - Monitor landings, size, age, gear, and harvest area in the reduction and bait fisheries, and determine age composition by area. Enhance biostatistical sampling of bait samples in purse seine fisheries for Virginia and New Jersey to improve stock assessment.
 - Study the ecological role of menhaden (predator-prey relationships, nutrient enrichment, oxygen depletion, etc.) in major Atlantic coast embayments and estuaries.
 - The feasibility of estimating year-class strength using biologically stratified sampling design should be evaluated. The efforts could be supported by process studies linking plankton production to abundance of young menhaden (need resources).
2. Evaluate use of coastal power plant impingement data as a possible means to estimate young-of-the-year menhaden abundance.
 - Monte Carlo simulations should be conducted to evaluate precision of VPA.
 - Alternative measures of effort, including spotter pilot logbooks, trip length, or other variables, should be evaluated. Spotter pilot logbooks should be evaluated for spotter plane search time, GPS coordinates, and estimates of school sizes observed by pilots.
 - Re-evaluate menhaden natural mortality, by age and response to changing predator population sizes.
3. Determine the effects of fish diseases (such as ulcerative mycosis and toxic dinoflagellates) on the menhaden stock.
 - Determine the effects of regulations on the fishery, the participants, and the stock.

- Growth back-calculation studies should be pursued to investigate historical trends in growth rate. The NMFS has an extensive database on scale growth increments that should be utilized for this purpose.
4. Monitor fish kills along the Atlantic coast and use the NMFS Beaufort Laboratory as a repository for these reports.
 5. Develop bycatch studies of menhaden by other fisheries. DISCARDS
 6. Periodically monitor the economic structure and sociological characteristics of the menhaden reduction industry.

Atlantic Menhaden Stock Assessment Report for Peer Review: Stock Assessment Report No. 04-01 (Supplement), February 2004 (ASMFC, 2004a)

Research and Monitoring Recommendations (number reflects relative ranking with 1 being the highest priority)

1. Conduct new size and age at maturity research by geographic regions along the Atlantic coast.
 - Develop coast wide tagging program to examine stock structure, spatial and temporal patterns in movement and migration, and to estimate exchange rate among geographic regions (i.e., inshore-offshore and latitudinal).
 - Develop a spatially explicit age-structured model to account for spatial and temporal differences in size/age distributions, size/age at maturity, and fishing effort and catchability rates.
 - Develop statistical sampling methods to improve catch and effort statistics in the recreational fishery. Evaluate extent of recreational netting of menhaden for bait purposes.
 - Monitor landings, size, age, gear, and harvest area in the reduction and bait fisheries, and determine age composition by area. Maintain biostatistical sampling of bait samples in purse seine fisheries for Virginia and New Jersey and enhance this sampling in Maryland, the Potomac, and North Carolina to improve stock assessment (ongoing).
 - Study the ecological role of menhaden (predator-prey relationships, nutrient enrichment, oxygen depletion, etc.) in major Atlantic coast embayments and estuaries (predator-prey interactions being evaluated through ASMFC multispecies efforts). Re-evaluate menhaden natural mortality by age and the response to changing predator population sizes (evaluated through MS model, incorporated variable M in assessment).

- Maintain and expand seine indices estimating size of recruiting year-classes of juveniles using fishery-independent survey techniques, particularly needed in mid-Atlantic region (ongoing research).
- Periodically monitor the economic structure and sociological characteristics of the menhaden reduction industry (Committee on Economic and Social Sciences - CESS).
- Determine the effects of regulations on the fishery, the participants and the stock (CESS ongoing project).
- Define local depletion in qualitative and quantitative terms. Determine environmental influences. Studies should not be limited to Chesapeake Bay.

2. Evaluate effects of selected environmental factors on growth, survival and abundance of juvenile and adult menhaden, particularly in Chesapeake Bay and other coastal nursery areas (NMFS/CBO ongoing project).

- Determine how loss/degradation of critical estuarine and nearshore habitat affects growth, survival, and abundance of juvenile and adult menhaden abundance.
- Evaluate use of coastal power plant impingement data as a possible means to estimate young-of-the-year menhaden abundance (ASMFC MSC project).

3. Determine the causes of fish diseases (such as ulcerative mycosis and toxic dinoflagellates) on the menhaden stock (ongoing research in MD/VA).

- Monitor fish kills along the Atlantic coast and use the NMFS Beaufort Laboratory as a repository for these reports (ongoing).
- Investigate the amount or extent of bycatch in the menhaden fishery. Evaluate whether a statistically valid observer program is needed to document possible sea turtle interactions with the various gear types. Develop bycatch studies of menhaden by other fisheries.
- Alternative measures of effort, including spotter pilot logbooks, trip length, or other variables, should be evaluated. Spotter pilot logbooks should be evaluated for spotter plane search time, GPS coordinates, and estimates of school sizes observed by pilots.

**Terms of Reference & Advisory Report to Atlantic Menhaden Stock Assessment
Peer Review: Stock Assessment Report No. 04-01, February 2004 (ASMFC, 2004b)**

1. Issue: There is no adult abundance index to tune the population model.

- Evaluate commercial purse seine fishery effort (vessel/weeks) series as a possible tuning index in the model. Evaluate any measure of effort contained in this or other data series.
- Evaluate the data collected in the Captain's Daily Fishing reports for an adult abundance index. If these data are not useful, explore the utility of a commercial fishery-based adult index, developed jointly with the fishermen, for future assessments.

2. Issue: Recent relative productivities of menhaden nursery areas coast wide are unknown.
 - Investigate if there are any existing studies that could assist in evaluating current productivity.
 - Develop protocols to quantify contribution of different nursery areas to the adult stock.
3. Issue: M-at-age is an improvement over constant M assumption. However, there is concern that not all key sources of mortality have been accounted for and little is known about the temporal patterns of mortality.
 - Identify key sources of non-fishing mortality for menhaden.
 - Enhance the coverage of the MSVPA to more predator and prey species.
 - Determine if there are temporal patterns in these sources.
 - Validate assumptions about applying results from MSVPA to the 1955-1980 period.
4. Issue: There have been large changes in size-at-age over the 1955-2002 period. These trends are not a problem for the model but could have an impact on forecasts.
 - Evaluate historical change in size (weight and length) at age using existing data (e.g., scale incremental widths).
5. Issue: There are patterns in residuals of numbers at age for commercial catch estimated by the model.
 - Investigate if the selectivity model is causing this pattern.
 - Look at spatial changes in fishing pattern as well as fish distribution.
6. Issue: Current fecundity estimates are from studies in the 1980s and earlier.
 - Update the fecundity-at-size estimates and maturity ogives.
7. Issue: Cannot address local depletion questions with the current model.
 - Investigate methods to determine the proportion of the stock that may reside in a particular area in any one season and whether regional reference points can be developed to address local depletion.
 - Extend these methods to track changes in distribution over time.
8. Issue: Control plot determination of overfishing/overfished is based on point estimates only.
 - Develop uncertainty measures or risk analysis for control plots.

9. Issue: It is difficult to distinguish between results of different models and model assumptions.
- Develop measures (goodness of fit and complexity) to screen multiple models.
10. Issue: The assessment model assumes a unit stock.
- Test this assumption using otolith microchemistry and/or genetic markers.

STRIPED BASS

ASMFC Special Report #81: Prioritized Research Needs in Support of Interjurisdictional Fisheries Management June 2004 (ASMFC, 2004c)

Prioritized Research Needs

1. Develop refined and cost-efficient coastal monitoring regime for striped bass stocks, including spawning stock biomass modeling and virtual population analysis (VPA).
2. Conduct sensitivity analysis on current state and federal fishery-dependent and -independent monitoring programs to determine which, if any, may be eliminated.
3. An evaluation of the overfishing definition should be made relative to uncertainty in biological parameters.
4. Simulation models should be developed to look at the implications of overfishing definitions relative to development of a striped bass population which will provide “quality” fishing. Quality fishing must first be defined.
5. Quota calculation methods should be refined which allow better estimates among various components of the fishery.
6. Examine differential reporting rates between commercial and recreational fishermen using high reward tags.
7. Develop studies to provide information on the magnitude of hook and release and bycatch mortality, including factors that influence their magnitude and means of reducing or eliminating this source of mortality.
8. Further study should be conducted on the discrepancy in ages between scale-based and otolith-based ages. Particular emphasis should be placed on comparisons with known age fish determined from coded wire tags. Comparisons should be made among age readers and areas.
9. Increase sea sampling of commercial fisheries, such as the dogfish gillnet fishery which may have high levels of discards.
10. Continue in-depth analysis of migrations, stock composition, etc. using mark-recapture data.
11. Continue to conduct research to determine limiting factors affecting recruitment and possible density implications.
12. Determine inherent viability of eggs and larvae.

13. Additional research should be conducted to determine the pathogenicity of the IPN virus isolated from striped bass to other warm water and marine species, such as flounder, menhaden, shad, largemouth bass and catfish.

**Report of the 36th Northeast Regional Stock Assessment Workshop (36th SAW):
Stock Assessment Review Committee (SARC) Consensus Summary of Assessments**

- Conduct a workshop to evaluate an appropriateness of scales in ageing old fish.
- Explore applicability of Bayesian framework to striped bass assessment.
- Develop the model that will combine VPA and tagging data.

WEAKFISH

ASMFC Special Report #81: Prioritized Research Needs in Support of Interjurisdictional Fisheries Management June 2004 (ASMFC, 2004c)

Prioritized Research Needs

High Priority

- Collect catch and effort data including size and age composition of the catch, determine stock mortality throughout the range, and define gear characteristics. In particular, increase length-frequency sampling, particularly in fisheries from Maryland and farther north.
- Develop latitudinal, seasonal, and gear specific age-length keys for the Atlantic coast. Increase sample sizes to consider gear specific keys.
- Derive estimates of discard mortality rates and the magnitude of discards for all commercial gear types from both directed and non-directed fisheries. In particular, quantify trawl bycatch, refine estimates of mortality for below minimum size fish, and focus on factors such as distance from shore and geographical differences. Update the scale – otolith comparison for weakfish.

Medium Priority

- Define reproductive biology of weakfish, including size at sexual maturity, maturity schedules, fecundity, and spawning periodicity. Continue research on female spawning patterns: what is the seasonal and geographical extent of "batch" spawning; do females exhibit spawning site fidelity?
- Conduct hydrophonic studies to delineate weakfish spawning habitat locations and environmental preferences (temperature, depth, substrate, etc.) and enable quantification of spawning habitat.
- Compile existing data on larval and juvenile distribution from existing databases in order to obtain preliminary indications of spawning and nursery habitat location and extent.
- Continue studies on mesh-size selectivity; up-to-date (1995) information is available only for North Carolina's gillnet fishery. Mesh-size selectivity studies for trawl fisheries are particularly sparse.
- Assemble socio-demographic-economic data as it becomes available from ACCSP.
- Additional investigation is needed in developing consistent otolith-based catch matrices including the EM algorithm.
- The impact of ageing errors and other statistical uncertainties in the catch-at-age matrix on virtual population analysis (VPA) should be included. Retrospective analyses are needed on all VPA approaches investigated.
- Develop a spawner recruit relationship

Summary Report by the Chair on the 40th North East Regional Stock Assessment
Review Committee (SARC)

Recommendations for Future Assessments

- There exists a considerable amount of information that in principle should permit an assessment using catch-at-age analysis. The basic information should be thoroughly evaluated as to its suitability for this approach.
- The commercial and recreational data should be examined with regard to its precision and accuracy, both in terms of the absolute estimates of catches and its age composition.
- The survey catch rates at age should be evaluated with respect to the spatial and temporal distribution of age groups over time to try to gain an understanding of why there are no consistent year-class signals within surveys.
- The survey distributions should be compared to observed changes in the pattern of the fisheries for weakfish to try to explain the inconsistencies in the trends observed in the different series.
- Work should be undertaken to validate the ageing methods employed.
- It is of primary importance to carefully evaluate the input data in terms of the information content regarding relative year-class strength. This evaluation could take the form of more statistically based GLM approach along the lines of the graphical analysis (i.e., Pope-Shepherd-Nicholson analysis of year-class, age and year effects). Alternatively the survey analysis approach suggested by Cook (1997) and subsequent developments under SURBA could have merit in this regard.
- It seems unlikely that statistical modeling will be able to reconcile the very different perspective on year-class strength between the fishery-independent surveys and the index obtained from the NMFS Marine Recreational Fisheries Statistics Survey. This problem should be given urgent attention through a focused research project that considers alternative hypotheses for the divergence.

The SARC was informed about a possible ecological explanation for the possible decline of the weakfish stock that requires review. Other explanations related to the survey indices and the recreational fishery statistics under the amended FMP also need to be given careful consideration.

BLUEFISH

ASMFC Special Report #81: Prioritized Research Needs in Support of Interjurisdictional Fisheries Management June 2004 (ASMFC, 2004c)

Prioritized Research Needs

1. Data needs:
 - a) Sampling of size and age composition of the fisheries by gear type and statistical area should be increased.
 - b) Commercial and recreational landings of bluefish should be targeted for biological data collection wherever possible.
 - c) Increase intensity of biological sampling of the NER commercial and coast wide recreational fisheries.
2. Continue research on species interactions and predator-prey relationships.
A scale-otolith age comparison study needs to be completed for bluefish.
3. Explore alternative methods for assessing bluefish, such as length-based and modified DeLury models.
4. Measures of CPUE under different assumptions of effective effort should be evaluated to allow evaluation of sensitivity of results.
5. Initiate fisheries dependent and independent sampling of offshore populations of bluefish during winter months.
6. Conduct research to determine the timing of sexual maturity and fecundity of bluefish.
7. Work should continue on catch and release mortality.
8. Any archived age data for bluefish should be aged and used to supplement North Carolina DMF keys in future assessments.
9. Conduct research on oceanographic influences on bluefish recruitment, including information on migratory pathways of larval bluefish.
10. Study tag mortality and retention rates for the American Littoral Society dorsal loop and other tags used for bluefish.
11. A coastal surf-zone seine study needs to be initiated to provide more complete indices of juvenile abundance.

12. Test the sensitivity of the bluefish assessment to assumptions concerning age-varying M , levels of age-0 discard, and the selection pattern.
13. Increase sampling frequencies when bluefish are encountered, especially when medium size fish are encountered.
14. Scientific investigations should be conducted on bluefish to develop an understanding of the long-term, synergistic effects of combinations of environmental variables on various biological and sociological parameters such as reproductive capability, genetic changes, and suitability for human consumption.
15. Studies on the interactive effects of pH, contaminants, and other environmental variables on survival of bluefish.
16. Investigate the relationship of epidemic dermatological disease of bluefish exhibited in the Tar-Pamlico estuary to environmental toxics or other parameters.
17. Investigate the distribution of adult bluefish (particularly the spring-spawned cohort) in the South Atlantic Bight and juvenile bluefish (including the pelagic stage); and develop precise information on the distribution and relative abundance of bluefish in inshore areas, especially estuaries and embayments.

41st Northeast Regional Stock Assessment Workshop (SAW-41) Stock Assessment Review Committee (SARC) Meeting, Chair's Report (NEFSC, 2005)

Short-term

- Continue to develop statistically appropriate models for this stock, including valuation of uncertainty and sensitivity. This modeling should also test sensitivity to data quality. The BTC should avoid double use of the data as model input.
- Evaluate the fishery-independent surveys used to tune the model with special emphasis on determining if the state surveys can be combined to yield better temporal and spatial representation of stock abundance. The BTC should encourage the states to coordinate their survey efforts for bluefish to improve the quality of data that can be obtained. We suggest a workshop to address this and other data issues.
- Evaluate the use of otolith and scale ageing of bluefish. We suggest this be a separate workshop to evaluate the best ageing structure and its reliability for stock assessment input. After the evaluation, intensify collection of age data from commercial and recreational fisheries, and evaluate the validity of combining age classes across years in an ALK.

Long-term

- Improve sampling coast wide by gear and fishery sector to obtain information with special emphasis on mid-size fish. This may require alternative fishery-independent assessment methodologies (such as lidar, archival tagging, sonar).
- Increase fishery-independent sampling to better represent the population's offshore and southern habitat.

Determine if discard mortality of 15% for the recreational fishery is accurate.

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